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SAFETY STUDIES OF LITHIUM-SULFUR DIOXIDE CELLS.(U)

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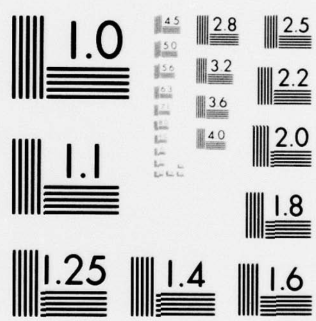

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Research and Development Technical Report

DELET-TR-78-0530-F

SAFETY STUDIES OF LITHIUM-SULFUR DIOXIDE CELLS

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NOVEMBER 1979

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Hermetically sealed SO_2 "D" cells were fabricated and tested to improve safety during use/abuse conditions. Cathodes and anodes were optimized to yield efficient and safe operation at $-20^{\circ}F$. Explosions were eliminated and venting was minimized when the cells were discharged at 2A constant current to 200% of the theoretical SO_2 content between $-20^{\circ}F$ and $+130^{\circ}F$. Discharge currents at 3.5A and above resulted in frequent but safe venting.

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INTRODUCTION

This report finalizes the results of work performed on Contract No. DAAB07-78-C-0530. The overall objective of the contract was to continue the exploration of the cause and effect relationship between Li/SO_2 cell performance and safety on the one hand and cell composition and design on the other. Initial efforts toward this objective were conducted under a previous contract (1).

A safe cell may be defined as one that undergoes no physical changes under use/abuse conditions. For this program, this interpretation was extended to cover a cell that vents gases or liquids without expelling an associated flame or metal fragments.

The conditions of intensive use/abuse to be used include:

- Forced discharge at high rate to 200% of SO_2 content
- Short circuit

These use/abuse conditions are the most likely from a practical viewpoint. Short circuit testing has been a Honeywell safety standard since the inception of high rate SO_2 cells. It provides immediate information as to the reliability of the vent for undischarged cells under the highest rate discharge. Short circuit testing is used to verify the ability of new internal designs to vent without an associated fire or flame.

The high rate forced discharge regime serves a dual purpose. The capacity to 2.0 volts is determined before the cell is driven into the possible unsafe negative region. The current is maintained for 200% of the theoretical SO_2 content to simulate a poor cell in a series-connected battery.

Overall, greater than 90% of the -20°F and room temperature 2A performance goals of 4.0 and 8.0 Ahrs., respectively, were achieved without venting on extended discharge on the initial program. A drop to as low as a 50% performance level resulted in venting, but without flame, as long as the cells remained lithium limited. Undesirable flame resulted from venting under these use/abuse conditions at Li/SO_2 ratios between 1.2 and 1.4 but in no case for the designs considered did explosions result.

The effort on this contract attempts to statistically verify these improvements and determine the limits of the design variables on both performance and safety. Design refinements were incorporated in the final build which characterizes the design capability at and beyond the performance goals.

Table I

BASELINE CELL PARAMETERS

ANODE		
Dimensions	:	24.5" x 1.75" x 0.007"
Capacity	:	10.5 Ahr
Collector	:	0.200" x 0.005" diagonal through length
CATHODE		
Dimensions	:	28" x 1.75" x 0.032"
Teflon Content	:	5%
Carbon & Teflon Wt/Density	:	9.0 g/0.35 g/cc
Theoretical Low Rate Capacity	:	13.0 Ahr*
ELECTROLYTE		
% SO_2	:	68%
SO_2 Theoretical Capacity	:	10.6 Ahr
SEPARATOR		
Type	:	Celgard
Layers between Electrodes	:	1
WRAP		
Configuration	:	Cathode Outside
Active Surface	:	580 cm^2
CELL BALANCE		
Li/SO_2	:	1.0
C/SO_2	:	1.2*

* Based on 1.44 Ahr/g mix theoretical.

DEVELOPMENT PROGRAM

a. TASK I - STATISTICAL VERIFICATION OF BASELINE CELLS

(1) Cell Design

Build and test data from Contract DAAB07-77-C-0459 was carefully reviewed. It was concluded the cells of 580 cm^2 surface area (and highest carbon loadings) represented the best efficiency and safety to date and would be the preferred baseline design. One intended change, a reduction of the diagonal nickel anode lead from 0.005 to 0.003" in thickness, was not implemented as it was not received in time for the build. The design parameters are shown in Table I.

(2) Cell Fabrication (Build 6)

A total of 42 cells were completed through the filling operation. The only difficulty encountered was in the wrapping operation which resulted in sporadic anode to cathode shorts. As expected from previous builds, the end of the 0.005" thick diagonal nickel lead was the source of the problem as it was too stiff to make the initial small radius bend at the beginning of the wrap without sometimes cutting through the separator. Several rewraps with added insulation over the end of the lead were necessary. Switching to 0.003" Ni for the next build alleviated this problem. The analysis of the average values, standard deviation and range for major build parameters for 30 randomly chosen cells from this build is shown in Table II. The low standard deviations indicate tight control on the materials and processing for the build.

(3) Discharge Tests

Table II

Baseline Cell Fabrication Statistics

Sample Size: 30

Parameter	$\bar{x}$ Average	δ Standard Deviation	R Range
Cathode Wt (Carbon & Teflon), g	9.07	0.24	8.63 - 9.5
Anode Theoretical Capacity, Ahr	10.47	0.08	10.30 - 10.65
SO_2 Theoretical Capacity, Ahr	10.61	0.05	10.44 - 10.69
Li/SO_2 Ratio	0.99	0.01	.96 - 1.00
(C & Tef)/SO_2 Ratio *	1.23	0.03	1.17 - 1.29

* Based on 1.44 Ahr/g mix theoretical.

Test Setup

Five cells were discharged at a time using one power supply through a series connection. The cells were contained in metal safety boxes, resting on insulation and separated by barriers to prevent sympathetic reactions. These cells were not clamped in a fixture which would act as a heat sink as were previous tests, but were open to air circulation. Voltage loads were connected to welded tabs and an insulated thermocouple was pressed against the case by glass tape. Individual cell voltages and temperatures were continuously monitored on chart recorders for 10 hours at 2A or nearly 200% of the theoretical SO_2 capacity.

Test Results

The 30 cells characterized in 2. 2 were split into two equal groups and discharged at 2A at room temperature and $-20^{\circ}F$ for 10 hours each. The discharge times to 2. 0V are shown in Table III. None of the 30 cells vented during the 10 hour discharge. Varying periods of voltage instability did occur after the voltage fell below zero and slight temperature increases were experienced during voltage instability. Representative discharges are shown in Figures 1 and 2.

The following reliability estimates were prepared from the above data:

- At room temperature, 95% of the baseline cells could be expected, at 90% confidence, to discharge longer than 4. 03 hours to 2. 0 V.

- At $-20^{\circ}F$, 95% of the baseline cells could be expected, at 90% confidence, to discharge longer than 1. 81 hours to 2. 0V; or 75% could be expected to discharge, at 90% confidence, longer than 2. 01 hours to 2. 0V.

- The reliability of a baseline cell to withstand a 2A discharge through 10 hours without venting is equal or greater than 85. 76% at 90% confidence.

Table III

TEST DATA SUMMARY BASELINE CELLS

CONSTANT CURRENT DISCHARGE TO 2.0 VOLTS

Cell #	Test Temperature	Time to 2.0 Volts	
DR 46	Ambient	4.10 Hrs.	$\overline{X}$ = 4.20 Hours
48		4.10	s = 0.0716 Hours
50		4.15	R = 0.20 Hours
54		4.15	n = 15
58		4.14	
61		4.21	
64		4.22	
66		4.09	
68		4.30	
70		4.26	
72		4.28	
75		4.28	
77		4.25	
81		4.24	
83		4.21	
DR 47	-20°F	2.35 Hrs.	$\overline{X}$ = 2.19 Hours
49		2.35	s = 0.161 Hours
51		2.05	R = 0.50 Hours
57		2.25	n = 15
60		2.26	
67		2.03	
69		2.15	
71		2.29	
73		2.04	
74		2.18	
76		2.38	
79		1.98	
80		2.25	
82		2.40	
84		1.88	

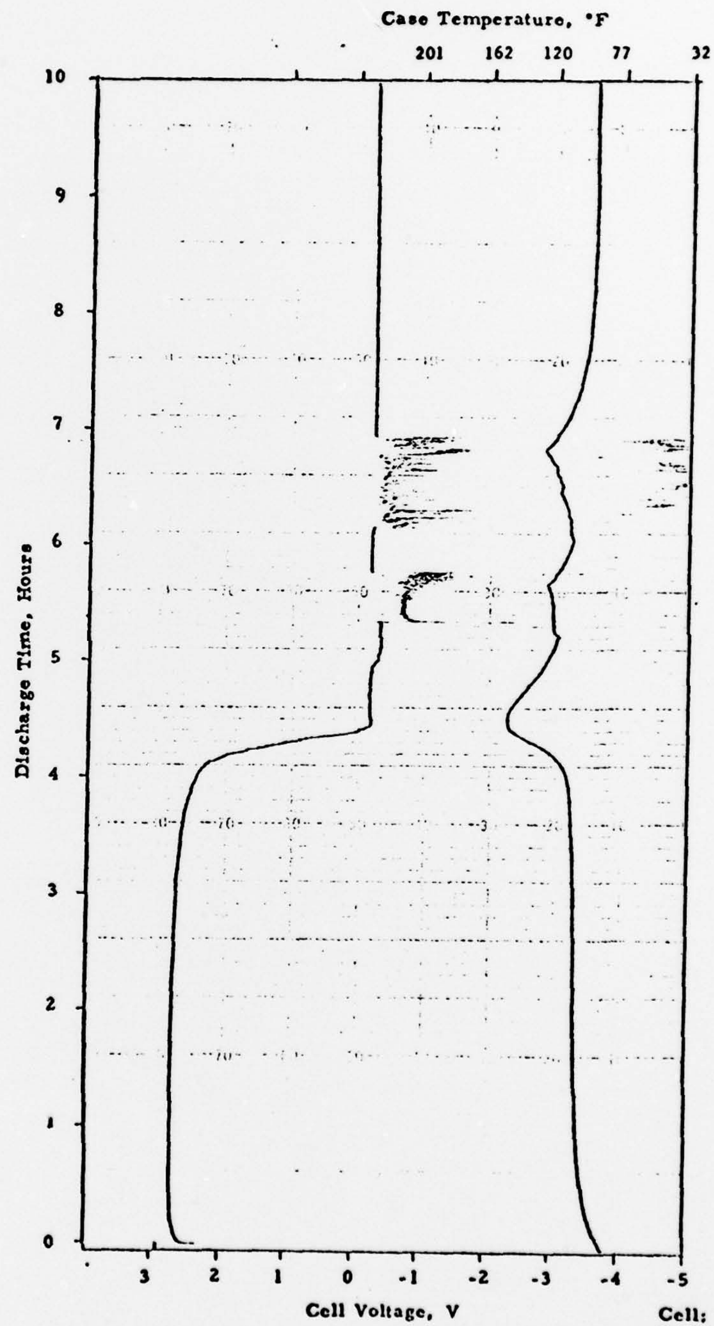


Figure 1 . Performance/Safety Tests

Cell: DR83
Build: 6
Load: 2A
Temp: RT

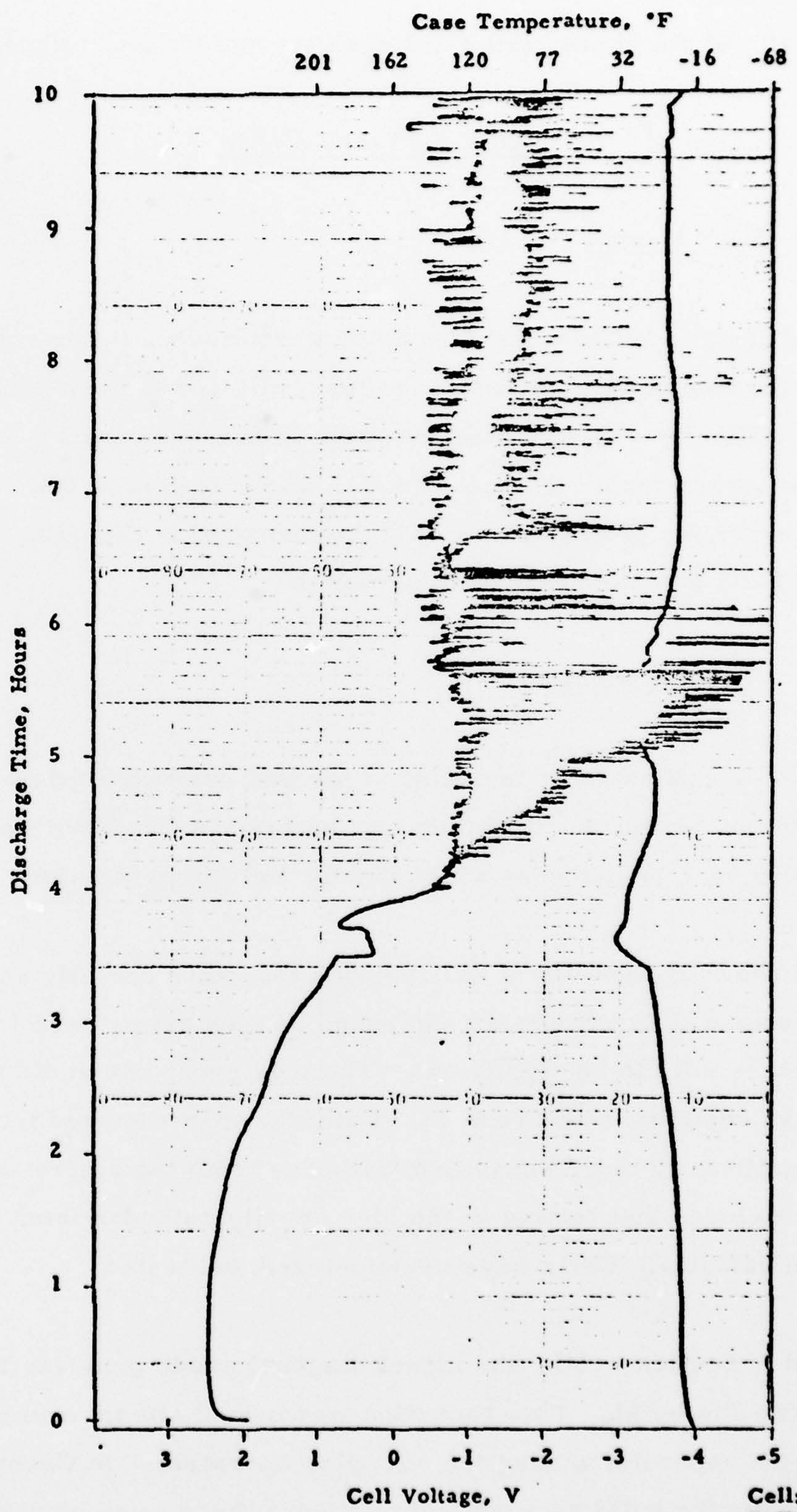


Figure 2. Performance/Safety Tests

Cell: DR60
Build: 6
Load: 2A
Temp: -20°F

The details of the above statistical analysis are shown in Appendix I.

b. TASK 2 - CATHODE OPTIMIZATION

(1) Cell Design

The cell design variables for this study were limited to the cathode. Table IV defines the design parameters of the test cells and the group numbers assigned. The obvious difficulty with this design matrix is in manufacturing cathodes that exactly meet the parameters. The combination of 5% Teflon, 0.032" thickness, 0.35 g/cc density and 9.0 g of cathode mix weight (Group 5) is the same as the baseline cells of Task I and was used as a control sample.

(2) Cell Fabrication

A total of 42 cells was manufactured for this evaluation (three cells of each design). As mentioned above, the difficulty encountered in this build was associated with processing various cathodes which nearly met the parameters set forth in Table IV.

Table V shows the details of the cathodes that were actually used in the tests. It was concluded that the mean and range of each group were isolated enough to allow test results to be significant. The only group which did not closely approximate the design objective was Group 14. Cathodes manufactured from the scaled-up blender were significantly more dense than cathodes from the slurry mix operation. However, it was concluded that testing of the high density cathodes from the full scale process would be valuable. Cells were manufactured and tested.

As noted in Section a. (2), the nickel diagonal anode lead was reduced from 0.005" to 0.003" for this build.. This reduction was indeed effective in reducing shorting through the separator during the wrapping operation. In Group 5A, 0.005" nickel was added to the build as a control to ensure there were no performance effects from the material change.

Table IV

Cathode Optimization Design Parameters

Separator:	:	1 Layer Celgard
Anode	:	24.5" x 1.75" x 0.007"
Cathode	:	28" x 1.75" x T
Wrap	:	Cathode Outside
Electrolyte	:	68% SO_2, 10.6 Ahr.
Quantity	:	3 Cells Each

Process	Teflon (%)	Thickness (inch)	Cathode Mix Wt. (g) Density (g/cc) 0.31	0.35	0.39
Slurry cake & blender	5	0.028 0.032	① 7.0 ④ 8.0	② 7.9 ⑤ 9.0	③ 8.8 ⑥ 10.0
Slurry cake & blender	7.5	0.028 0.032	⑦ 7.0 ⑩ 8.0	⑧ 7.9 ⑪ 9.0	⑨ 8.8 ⑫ 10.0
Slurry cake & blender	3	0.032	---	⑬ 9.0	---
Littleford Full Scale Mixer (25 lb. batch)	5	0.032	---	⑭ 9.0	---

Note: Circled numbers are group numbers

Groups submitted for porosimetry analysis - 2, 4, 5, 6, 8, 10, 11, 12, 13 & 14.

Table V

Cathode Optimization Task
Design vs Actual Cathode Parameters

Cathode Design Parameters				Build Data						
Group	Teflon %	Thick. in	Density gm/cc	Cell No.	Carbon/Teflon gm	Carbon/Teflon gm/cc	Anode Ahrs	SO_2 Ahrs	C/SO_2*	Li/SO
1	5.0	0.028	0.31	DR89	7.05	0.325	10.73	10.65	0.95	1.01
				DR91	7.00	0.323	10.53	10.56	0.95	1.00
				DR93	7.10	0.327	10.53	10.66	0.96	0.99
2	5.0	0.028	0.35	DR94	8.05	0.358	10.37	10.67	1.09	0.97
				DR96	8.10	0.360	10.37	10.60	1.10	0.98
				DR97	7.85	0.349	10.65	10.59	1.07	1.01
3	5.0	0.028	0.39	DR99	9.05	0.402	10.37	10.61	1.23	0.98
				DR101	8.80	0.391	10.37	10.67	1.19	0.97
				DR103	8.69	0.386	10.34	10.61	1.17	0.97
4	5.0	0.032	0.31	DR104	8.10	0.315	10.30	10.62	1.10	0.97
				DR105	8.00	0.302	10.34	10.38	1.10	1.00
				DR106	8.00	0.302	10.30	10.68	1.09	0.97
5	5.0	0.032	0.35	DR109	9.25	0.354	10.34	10.52	1.27	0.98
				DR110	8.95	0.343	10.30	10.63	1.21	0.97
				DR111	9.21	0.347	10.34	10.61	1.25	0.97
5A	5.0	0.032	0.35	DR114	9.10	0.348	10.45	10.61	1.24	0.99
	(0.005" Ni anode lead)			DR115	9.05	0.347	10.45	10.51	1.24	0.99
				DR117	8.84	0.355	10.37	10.61	1.20	0.98
6	5.0	0.032	0.39	DR119	9.70	0.366	10.34	10.68	1.31	0.97
				DR121	9.70	0.366	10.37	10.49	1.33	0.99
				DR123	9.70	0.383	10.30	10.65	1.31	0.97
7	7.5	0.028	0.31	DR125	6.90	0.296	11.62	10.68	0.93	1.09
				DR127	6.80	0.302	11.58	10.68	0.92	1.08
				DR128	6.90	0.296	10.65	10.67	0.93	1.00
8	7.5	0.028	0.35	DR129	7.95	0.346	10.34	10.50	1.09	0.98
				DR130	7.89	0.364	10.34	10.60	1.07	0.98
				DR132	8.16	0.376	10.34	10.53	1.12	0.98
9	7.5	0.028	0.39	DR134	9.40	0.403	10.61	10.70	1.27	1.00
				DR135	8.60	0.382	10.61	10.57	1.17	1.00
				DR136	9.40	0.403	10.57	10.47	1.29	1.01
10	7.5	0.032	0.31	DR139	7.75	0.311	10.49	10.57	1.06	0.99
				DR140	7.80	0.303	10.45	10.63	1.06	0.98
				DR142	7.90	0.307	10.45	10.66	1.07	0.99
11	7.5	0.032	0.35	DR144	8.75	0.340	10.37	10.60	1.19	0.98
				DR145	8.80	0.342	10.37	10.65	1.19	0.97
				DR147	8.85	0.355	10.41	10.56	1.22	0.99
12	7.5	0.032	0.39	DR149	10.39	0.404	10.30	10.58	1.41	0.97
				DR150	9.92	0.386	10.37	10.60	1.35	0.98
				DR152	10.26	0.399	10.45	10.49	1.41	1.00
13	3.0	0.032	0.35	DR159	7.90	0.317	10.34	10.66	1.07	0.97
				DR160	8.15	0.327	10.34	10.61	1.11	0.97
				DR161	8.35	0.315	10.49	10.46	1.15	1.00
14	5.0	0.032	0.35	DR164	11.96	0.480	10.41	10.63	1.62	0.98
	(Scale-up)			DR166	11.62	0.466	11.42	10.65	1.57	1.07
				DR168	11.16	0.463	10.92	10.58	1.52	1.03

* Based on 1.44 Ahr/g mix theoretical.

Full Scale Cathode Process

The roll formed cathodes manufactured for this Task utilized a process concept developed under a Manufacturing Technology Contract for Li/SO_2 cells. (2) A concept drawing of this operation is shown in Figure 3. Laboratory equipment was used for most of the cathodes; however, Group 14 utilized full scale mixing and micronizing equipment.

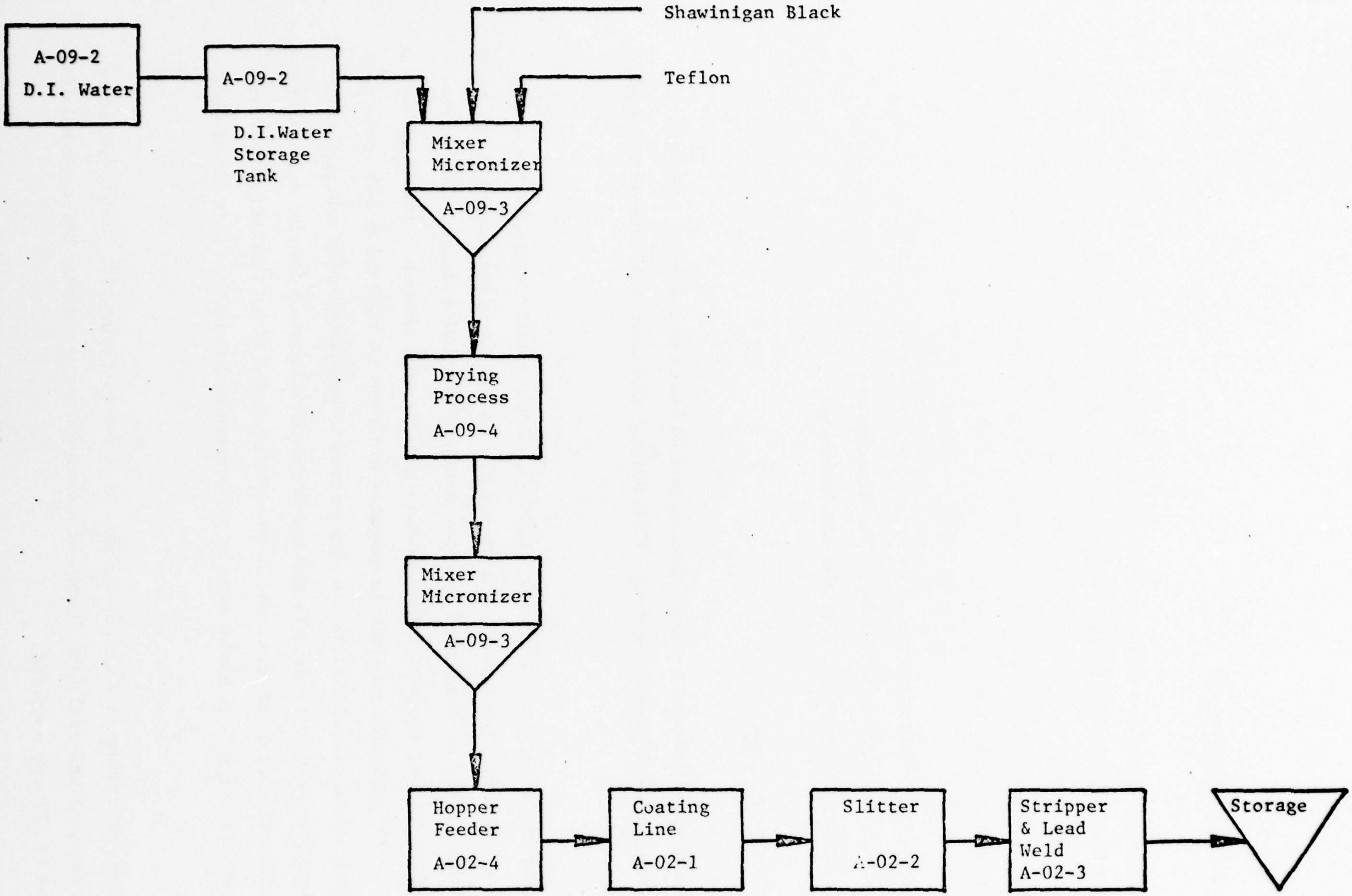
The intent of this evaluation was to determine if any performance variation was introduced by full scale processing. The discussion in d. (1)-Cathodes, of the report indicates the problems and ultimate solutions.

(3) Test Results

The 42 cells manufactured were all discharged 10 hours at a 2 amp. constant current rate in a -20°F environment. Cell voltage and case wall temperature were recorded.

The results of the tests are shown in Table VI. Representative graphs are shown in Figures 4 thru 9. The cathode variations had no impact in the ability of the cells to carry the 2A load as evidenced by close range of the peak voltage. The introduction of the thinner diagonal nickel anode collector was also not a factor as Group 5 with the 0.003" collector compared favorably to Group 5A with the 0.005" collector. Teflon content and cathode thickness also proved to be statistically insignificant. Of minor significance was the density and the interaction between density and thickness. The significance was these parameters were interpreted as an indirect measure of the carbon mix weight which was once again determined to be the most significant variable.

The capacity vs carbon mix weight for this is shown in Figure 10. Using linear regression analysis and excluding Group 14 and another from Group 5A, a correlation coefficient of .72 was obtained.



CATHODE PROCESS, FINAL CONCEPT

Figure 3

Table VI

Cathode Optimization Test Results

For 0.39 g/cc Cathodes

Load: 2A Constant Current
Discharge Time: 10 hrs.
Temperature: -20°F

Cathode Design Parameters				Actual Cath. Data			Test Results				
Group	Teflon %	Thick. in.	Density gm/cc	Cell No.	Carbon/Teflon gm	Carbon/Teflon gm/cc	Peak Voltage	Time to 2V Hours	Venting Before 10 Hrs.	Vent Temp. °F	Porosimetry Analysis
3	5.0	0.028	0.393	DR99	9.05	0.402	2.51	2.3			
				DR101	8.80	0.391	2.53	2.3			
				DR103	8.69	0.386	2.52	2.3			
6	5.0	0.032	0.372	DR119	9.70	0.366	2.52	2.6			
				DR121	9.70	0.366	2.50	2.4			Yes
				DR123	9.70	0.383	2.55	2.3			
9	7.5	0.028	0.390	DR134	9.40	0.403	2.53	2.3			
				DR135	8.60	0.382	2.49	2.1			
				DR136	9.40	0.403	2.52	2.4			
12	7.5	0.032	0.396	DR149	10.39	0.404	2.50	2.4			
				DR150	9.92	0.386	2.50	2.3			Yes
				DR152	10.26	0.399	2.50	2.5			
		Averages			9.47	0.389	2.51	2.35			

Table VI (continued)

Cathode Optimization Test Results

For 0.39 g/cc Cathodes

Load: 2A Constant Current
Discharge Time: 10 hrs.
Temperature: -20°F

Cathode Design Parameters				Actual Cath. Data			Test Results				
Group	Teflon %	Thick. in.	Density gm/cc	Cell No.	Carbon/Teflon gm	Carbon/Teflon gm/cc	Peak Voltage	Time to 2V Hours	Venting Before 10 Hrs.	Vent Temp. °F	Porosimetry Analysis
2	5.0	0.028	0.350	DR94	8.05	0.358	2.42	2.1			
				DR96	8.10	0.360	2.51	2.15			Yes
				DR97	7.85	0.349	2.53	1.75			
5	5.0	0.032	0.348	DR109	9.25	0.354	2.52	2.4	Yes	72	
				DR110	8.95	0.343	2.49	2.3	Yes	37	Yes
				DR111	9.21	0.347	2.50	2.4			
5A	5.0	0.032	0.350	DR114	9.10	0.348	2.57	2.35			
(0.005" Ni anode lead)				DR115	9.05	0.347	2.50	2.35			
				DR117	8.84	0.355	2.50	1.7			
8	7.5	0.028	0.362	DR129	7.95	0.346	2.53	2.05			
				DR130	7.89	0.364	2.50	1.8	Yes	68	Yes
				DR132	8.16	0.376	2.51	1.9			
11	7.5	0.032	0.345	DR144	8.75	0.340	2.49	2.4			
				DR145	8.80	0.342	2.52	2.15			Yes
				DR147	8.85	0.355	2.50	2.2			
13	3.0	0.032	0.320	DR159	7.90	0.317	2.50	1.85	Yes	32	
				DR160	8.15	0.327	2.50	1.85			Yes
				DR161	8.35	0.315	2.47	1.8			
14	5.0	0.032	0.470	DR164	11.96	0.480	2.50	2.3			
				DR166	11.62	0.466	2.58	2.25			Yes
				DR168	11.16	0.463	2.50	2.1	Yes	39	
		Average (Excluding Group 14)			8.51	0.347	2.50	2.08			
		Group 14 Average			11.58	0.470	2.53	2.22			

Table VI (continued)

Cathode Optimization Test Results

For 0.39 g/cc Cathodes

Load: 2A Constant Current
Discharge Time: 10 hrs.
Temperature: -20°F

Cathode Design Parameters				Actual Cath. Data			Test Results				
Group	Teflon %	Thick. in.	Density gm/cc	Cell No.	Carbon/Teflon gm	Carbon/Teflon gm/cc	Peak Voltage	Time to 2V Hours	Venting Before 10 Hrs.	Vent Temp. °F	Porosimetry Analysis
1	5.0	0.028	0.310	DR89	7.05	0.325	2.55	1.7	Yes	60	
				DR91	7.00	0.323	2.51	1.85	Yes	186	
				DR93	7.10	0.327	2.57	1.8			
4	5.0	0.032	0.306	DR104	8.10	0.315	2.50	2.1			
				DR105	8.00	0.302	2.50	1.9			
				DR106	8.00	0.302	2.51	2.1			
7	7.5	0.028	0.310	DR125	6.90	0.296	2.48	1.7			
				DR127	6.80	0.302	2.49	1.7			
				DR128	6.90	0.296	2.50	1.8			
10	7.5	0.032	0.307	DR139	7.75	0.311	2.51	1.9			
				DR140	7.80	0.303	2.50	1.9			
				DR142	7.90	0.307	2.48	2.0			
			Averages		7.44	0.309	2.51	1.87			

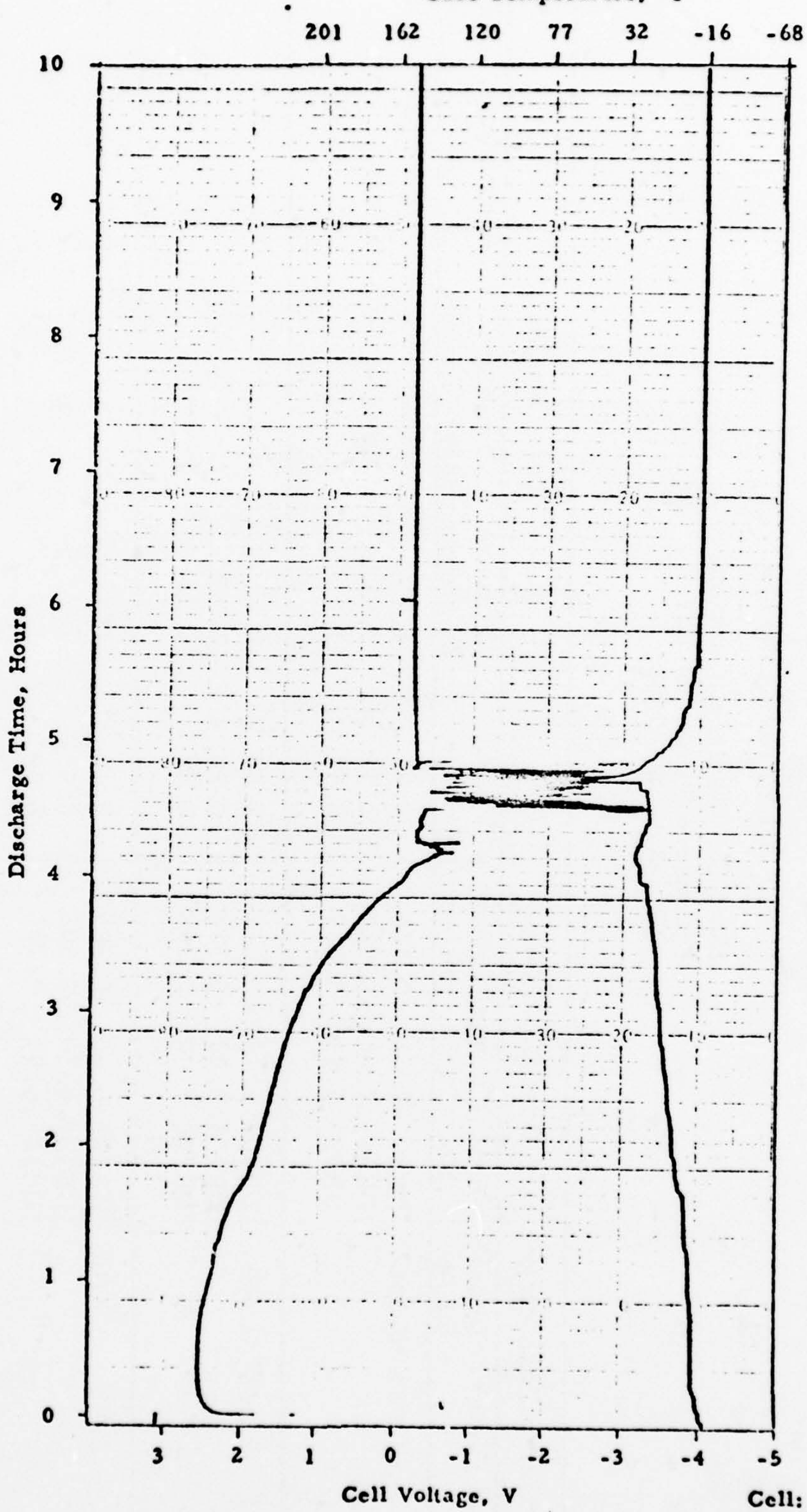


Figure 4. Performance/Safety Tests

Cell: DR89
Build: 7
Load: 2A
Temp: -20°F

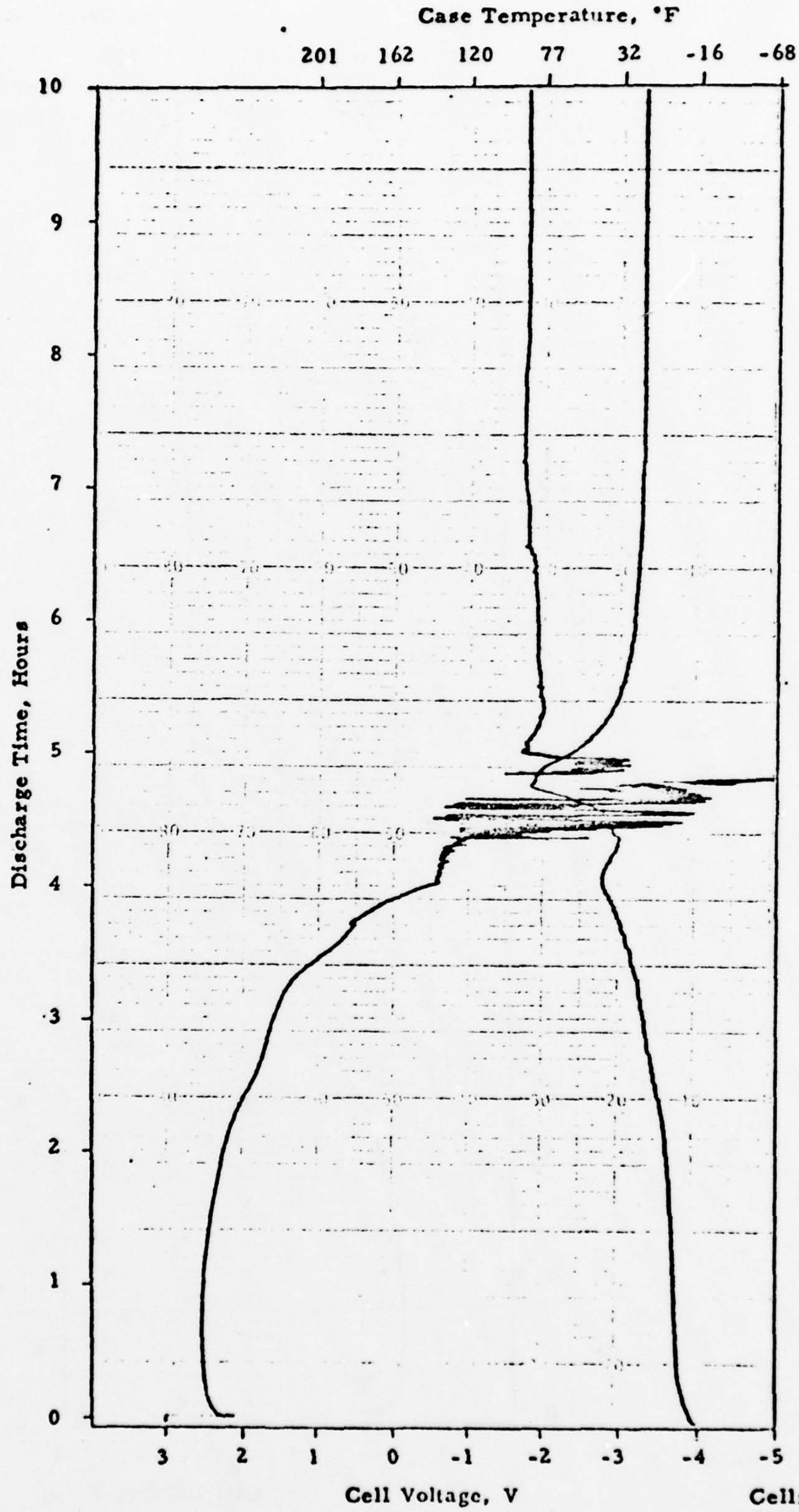
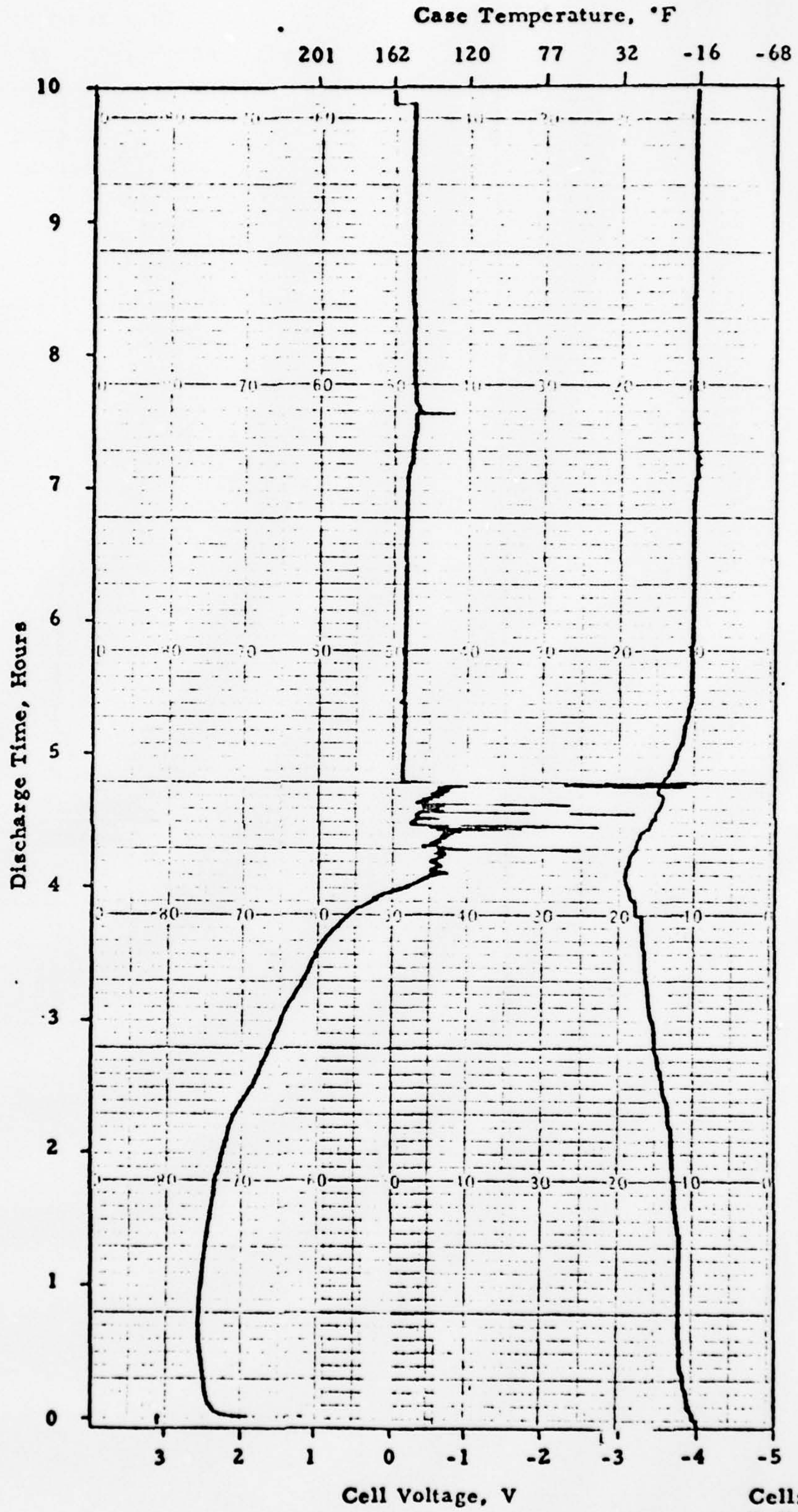


Figure 5 . Performance/Safety Tests

Cell: DR III
Build: 7
Load: 2A
Temp: -20°F



Cell: DR114
Build: 7
Load: 2A
Temp: -20°F

Figure 6 . Performance/Safety Tests

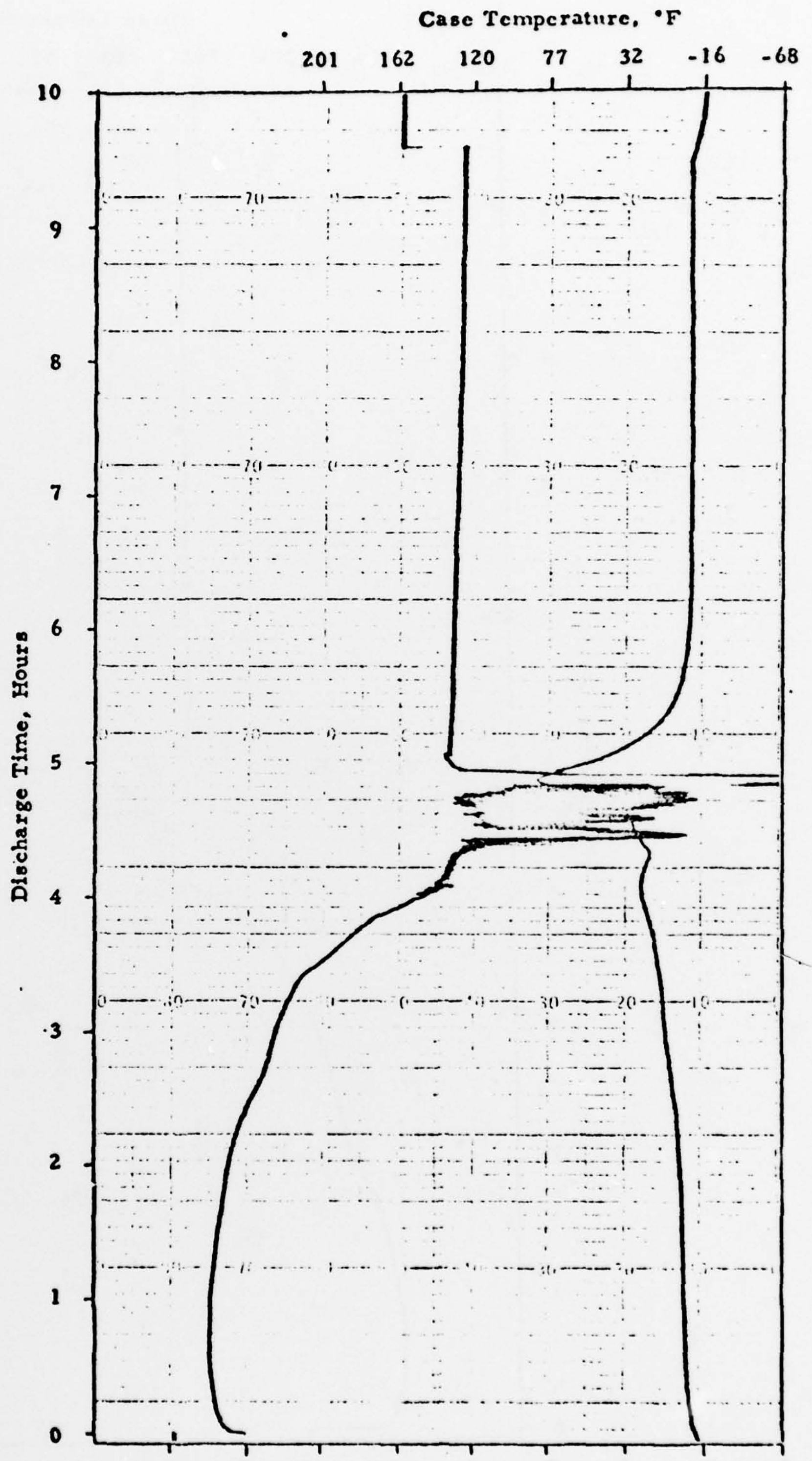
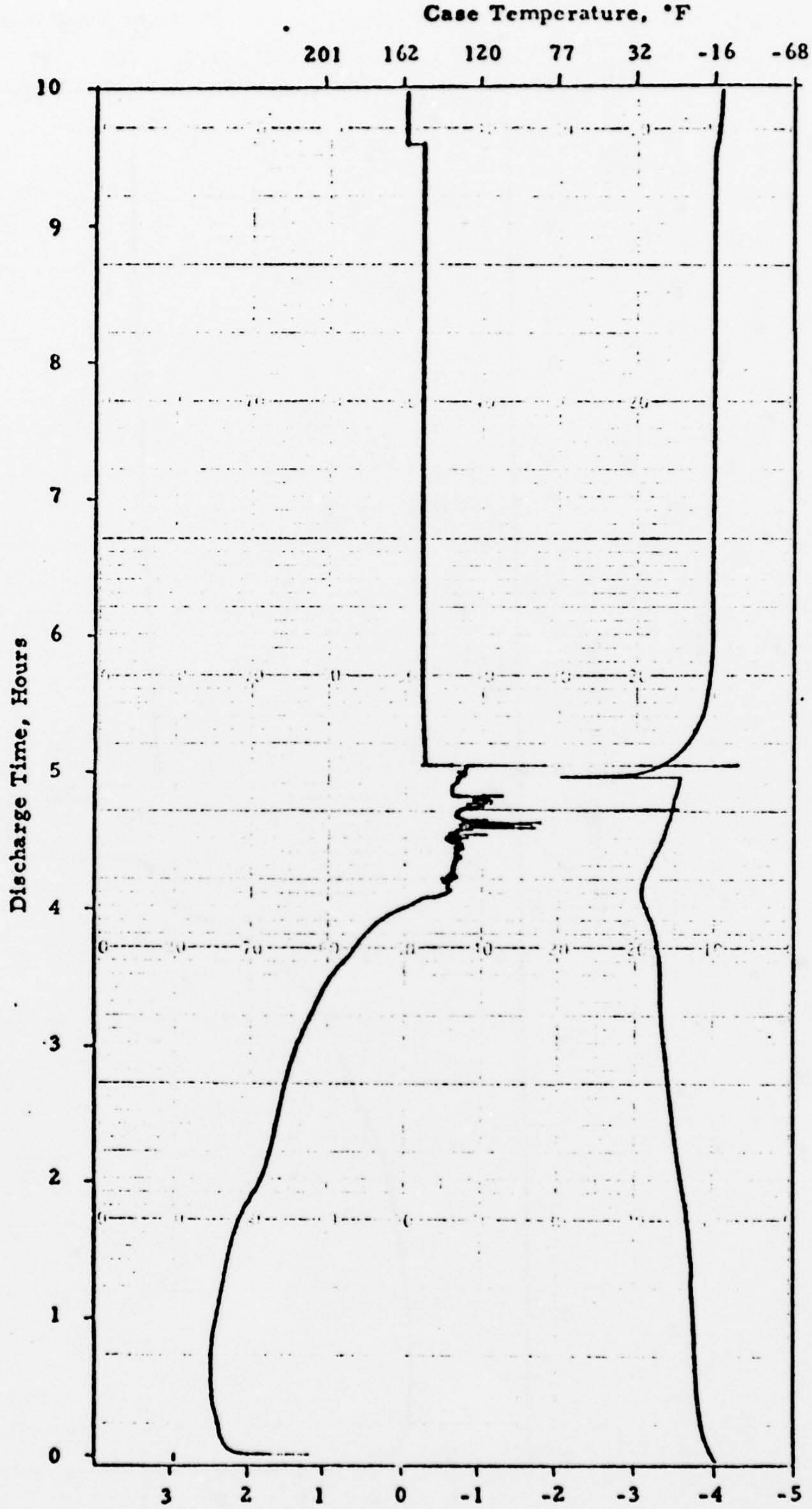


Figure 7 . Performance/Safety Tests

Cell: DR144
Build: 7
Load: 2A
Temp: -20°F



Cell: DR159
Build: 7
Load: 2A
Temp: -20°F

Figure 8 . Performance/Safety Tests

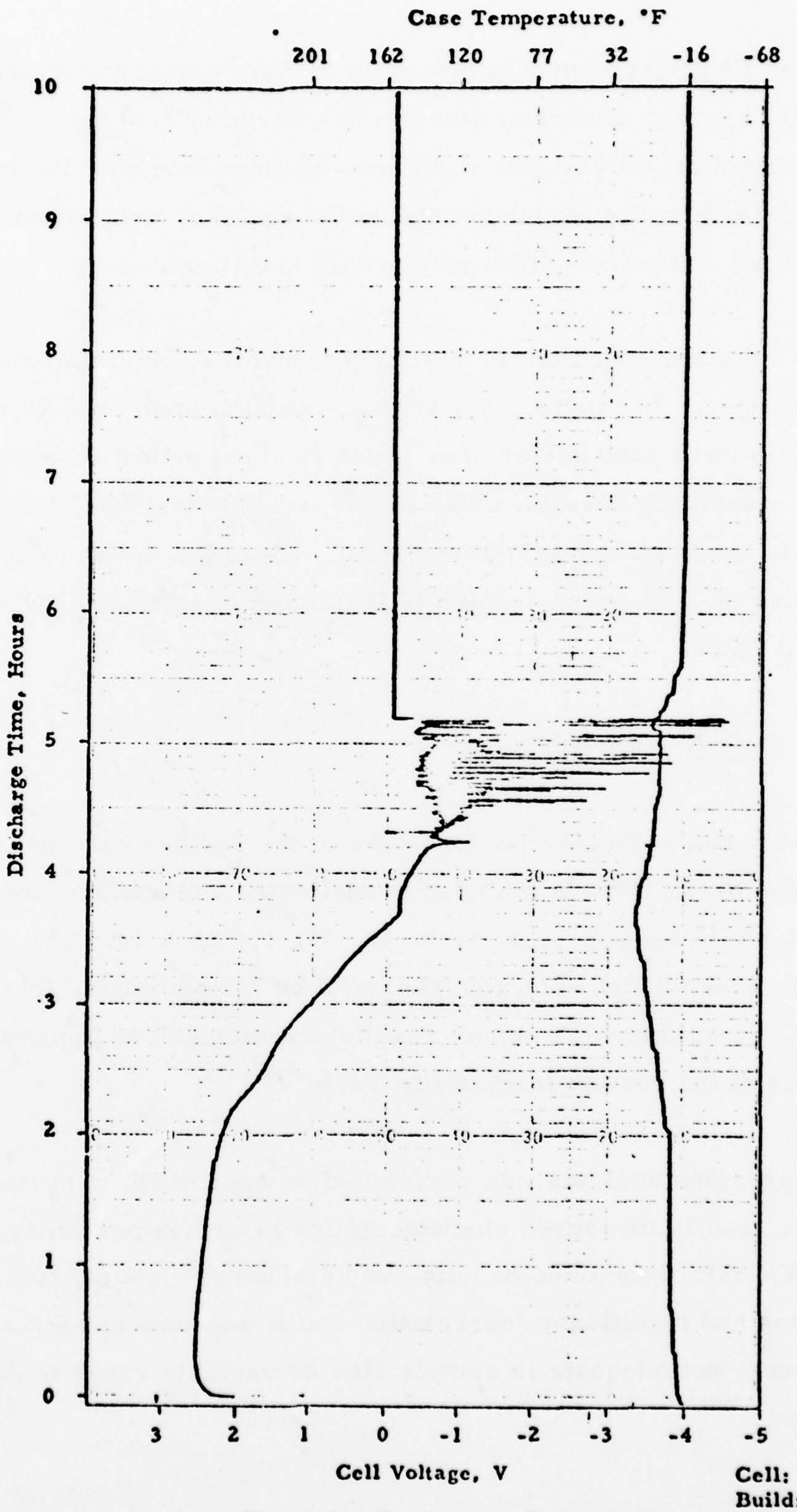


Figure 9. Performance/Safety Tests

Cell: DR 166
Build: 7
Load: 2A
Temp: -20°F

This linear fit projects an increase of 0.49 Ahr. per gram of carbon mix between 6.9 and 10.2 grams of carbon mix at a discharge of 2.0A at -20°F. Group 14 was excluded from this anlysis due to its non-conformance with the trend of the data. A detrimental effect on the cathode due to the scale-up process and the limitation due to either lithium and/or SO_2 efficiency may be possible causes.

The cells were continued on the discharge until they vented or the 10 hrs. at 2A were completed. The pattern for venting remains unclear. Of the seven cells that vented, four were poor performers which is consistent with earlier tests (1) but two were essentially baseline cells which previously showed improved safety by not showing any venting (a. (3) Test Setup). Six of the seven cells vented with a case temperature of 72°F or less which is indicative of a low energy reaction without associated flame.

(4) Porosimetry Analysis

In addition to evaluating the performance of the various cathode configurations, the optimization of the cathode included porosimetry and surface area measurements of cathodes from Groups 2, 4, 5, 6, 8, 10, 11, 12, 13 & 14. The measurements were taken from the cathodes shown in Table VII by Micrometrics Instrument Corporation, Norcross, Georgia and the report results are included in Appendix 2 of this report. A summary of the results is shown in Table VIII.

Linear regression analysis was performed on each of the reported characteristics against the readily measured characteristics of Teflon percentage, cathode thickness, carbon/TFE mix weight and density, and discharge capacity to 2.0 volts. None of the analyses had significant correlation and it was concluded that the characteristics reported were not adequate in sample size or variable range to determine their importance.

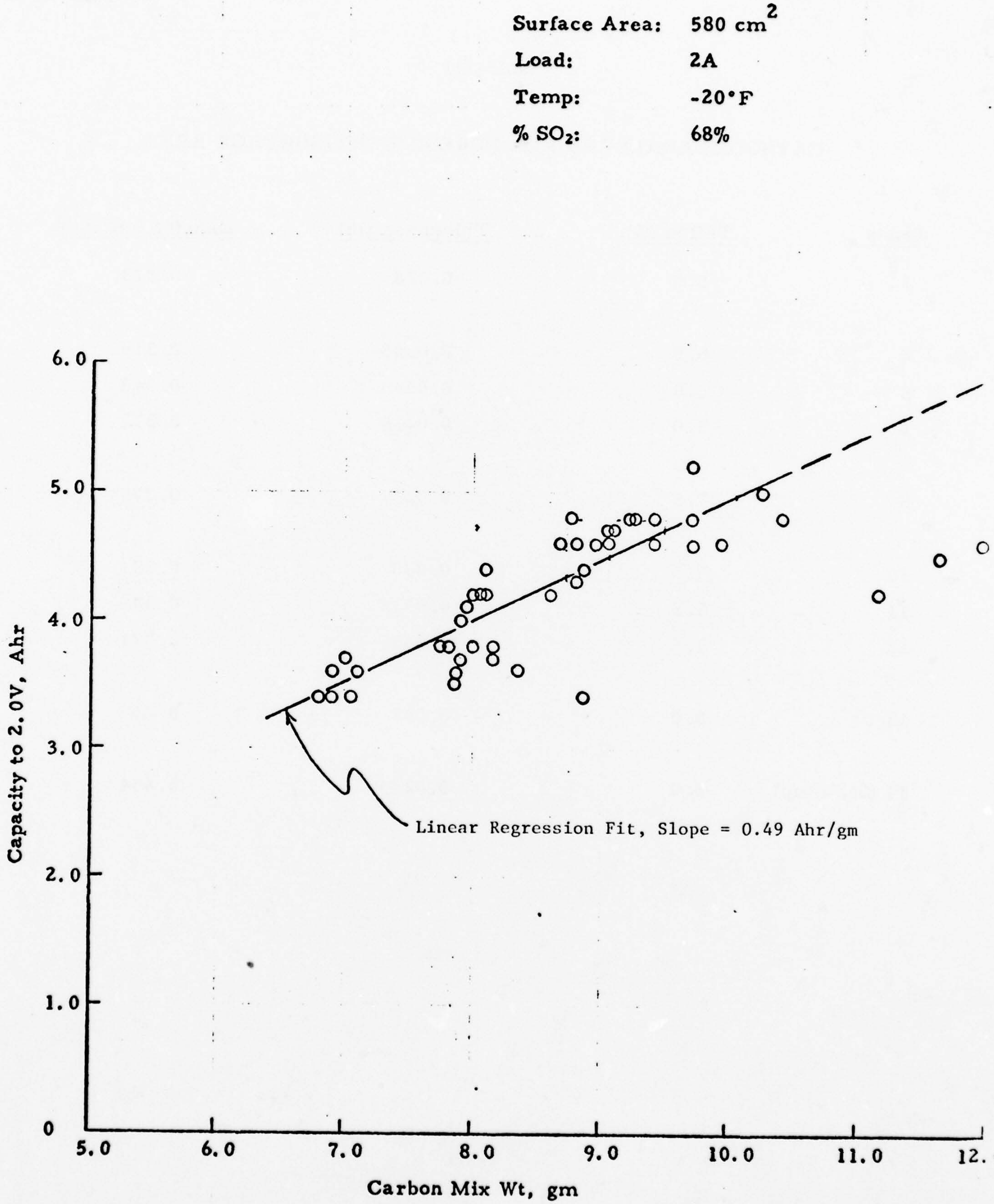


Figure 10

Capacity vs. Carbon Mix Weight

Table VII

CATHODES ANALYZED FOR POROSIMETRY/SURFACE AREA

Group	Teflon (%)	Thickness (in)	Density (gm/cc)
2	5.0	0.028	0.373
4	5.0	0.0325	0.318
5	5.0	0.033	0.348
6	5.0	0.0235	0.372
8	7.5	0.028	0.375
10	7.5	0.030	0.321
11	7.5	0.0315	0.349
12	7.5	0.033	0.371
13	3.0	0.032	0.315
14 (Scale-up)	5.0	0.0295	0.454

Table VIII

POROSIMETRY RESULTS

Sample Identification	Specific Surface Area (m^2/g)	Net Pore Volume (cc/g)	Average Pore Diameter (microns)	Bulk Density (g/cc)	Density at 50,000 psi (g/cc)	Porosity (%)
Group 2	20.719	1.191	0.46	0.47	1.08	56.4
Group 4	29.903	1.322	0.48	0.52	1.66	68.8
Group 5	31.001	1.036	0.26	0.67	2.22	69.7
Group 6	31.171	1.593	0.36	0.44	1.46	69.9
Group 8	28.784	0.829	0.54	0.55	1.01	45.7
Group 10	27.190	1.502	0.62	0.48	1.77	72.7
Group 11	29.772	1.825	0.76	0.42	1.76	79.3
Group 12	30.068	1.483	0.39	0.46	1.45	68.2
Group 13	31.196	1.557	0.58	0.45	1.47	69.6
Group 14	32.077	1.309	0.32	0.47	1.24	61.8

c. TASK III - Li/SO_2 RATIO EVALUATION FOR SAFETY

(1) Cell Design

Cells with a Li/SO_2 ratio design range from 0.9 to 1.1 were evaluated for performance and safety. The chosen range was based on a nominal Li/SO_2 ratio of one from the baseline cell, the current tolerance of supplied lithium and an assumed close control of SO_2 content in a production operation. Two means of lithium content control were implemented: variation of the anode length and the alloying of the lithium with 10% aluminum. Varying the length results in a corresponding change in effective electrode surface area, while alloying can reduce the lithium content without affecting the total surface.

The matrix for the Li/SO_2 ratio evaluation tests are shown in Table IX. With the electrode length varying, it was attempted to maintain a constant carbon/Teflon weight of 9.0 gms. by adjusting the cathode thickness at the design density of 0.35 gm/cc.

(2) Lab Cell Test with 10% Aluminum/90 Lithium Alloy

Cell Construction

The lab cell (gasketed seals) consisted of a standard 0.030" thick, 5% Teflon, roll formed cathode, one layer of Celgard separator, an 0.007" thick anode of 90% lithium, 10% aluminum and an electrolyte of 64.4% SO_2. The electrode surface area was 0.5 in^2.

Test Results

Two current-voltage scans were performed with the results shown in Table X and Figure 11. A short through the separator following the scans prevented the planned 3 mA/cm^2 discharge for capacity. These results indicated that after an initial equalization period for wetting and lithium film removal, the lithium aluminum alloy performed exceptionally well to high current densities and no voltage problems were anticipated for Task III cells.

Table IX

Li/SO_2 Ratio Design Parameters

Separator	:	1 Layer Celgard
Anode	:	L x 1.75" x 0.007"
Cathode	:	L x 1.75" x T
Wrap	:	Cathode Outside
Electrolyte	:	68% SO_2, 10.6 Ahr
Quantity	:	3 Cells Each

	Li/SO_2 Ratio											
	0.9				1.0				1.1			
	Li	Cathode			Li	Cathode			Li	Cathode		
% Al	L (in)	L (in)	T (in)	Wt (gm)	L (in)	L (in)	T (in)	Wt (gm)	L (in)	L (in)	T (in)	Wt (gm)
0	22	26	0.036	9.0	24.5	28	0.032	9.0	27	30.5	0.028	9.0
10	24.5	28	0.032	9.0	27.0	30.5	0.028	9.0	30.0	34	0.025	9.0

Table X

Current Voltage Scan - 10% Al Anode

Load Ω	Current* mA	Current* Density mA/cm^2	Scan 1 Voltage V	Scan 2 Voltage V
1000	2.9	.9	2.76	2.89
500	5.8	1.8	2.71	2.88
250	11.4	3.5	2.63	2.85
100	27.9	8.6	2.66	2.79
50	54.0	16.7	2.58	2.70
25	103.2	31.9	2.54	2.58
10	231.0	71.5	2.34	2.31

*Based on Scan 2 Voltages

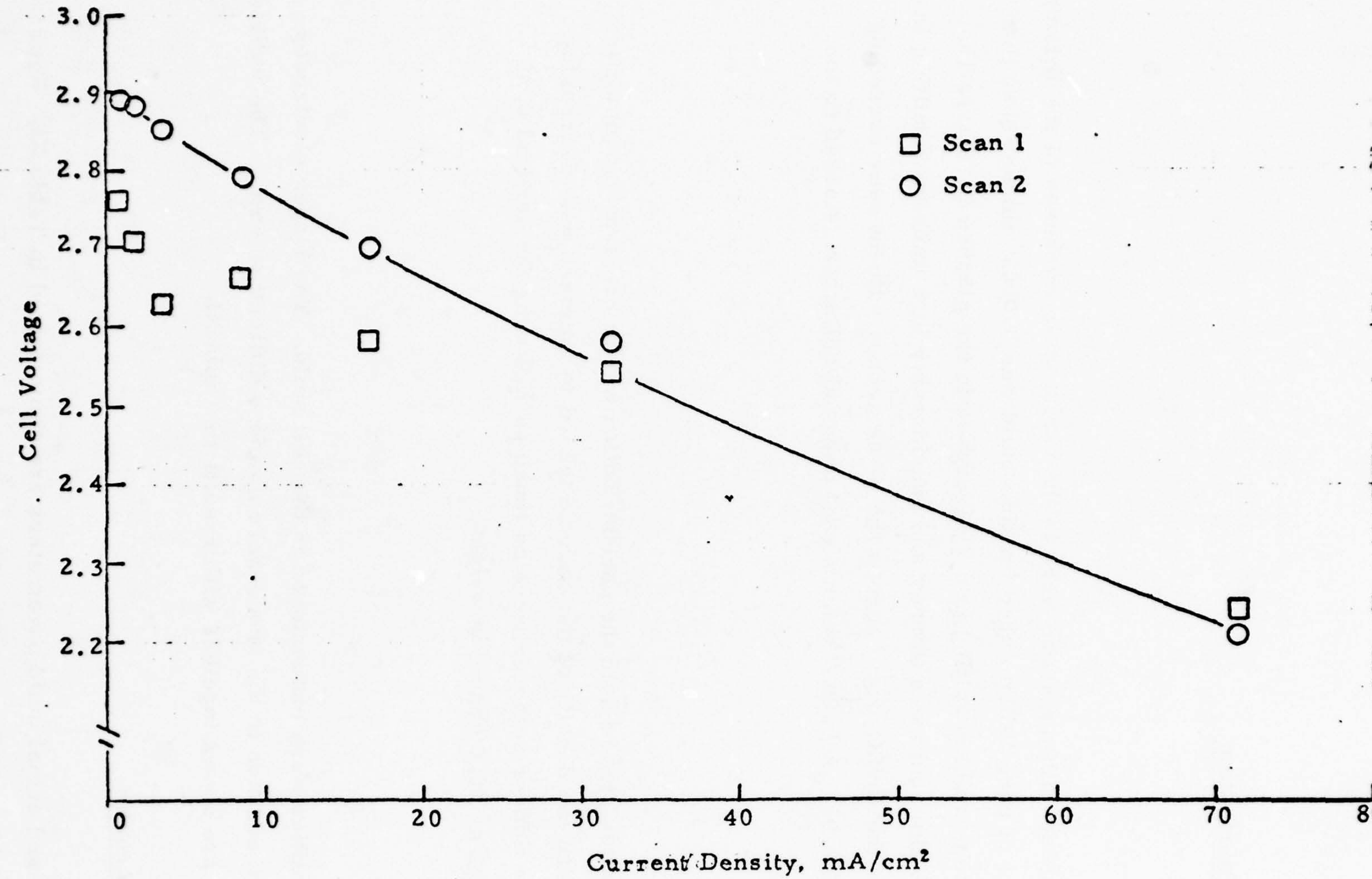


Figure 11

Current-Voltage Scan - 10% Al Anode

(3) Cell Fabrication

Anode

The build difficulties with the anode were in the variation in thickness of the lithium foil. The new lot of pure lithium used for this build was 0.0005" thicker than that used in the previous build resulting in a 7% increase in the planned Li/SO_2 ratio. The foil with 10% aluminum was thinner and considerably less uniform resulting in an overlapping of the Li/SO_2 ratio across the three groups without ever exceeding a Li/SO_2 ratio of 0.96. A 0.003" thick nickel diagonal collector, stacked to the anode was used.

Cathodes

Although it was attempted to hold the carbon/Teflon weight constant, some difficulty was encountered as the density of the cathode tended to increase with decreasing thickness and the thinner cathodes were as much as 15% over the nominal 0.35 gm/cc and as high as 10.0 grams in weight.

Activation

No further difficulties were encountered in the cell build. The longer electrodes and the aluminum addition to the anode were no more difficult to wrap. The individual cell parameters are shown together with results in Table XI.

(4) Test Results

The test results and actual build parameters are summarized in Table XI. Representative graphs are shown in Figures 12 - 17.

Table XI

Li/SO_2 Ratio Evaluation Build and Test Results

Load: 2A Constant Current

Temperature: $-20^{\circ}F$

Design Parameters			Build Data								Test Results			
Group	Al %	Surface Area cm^2	Cell No.	Cathode Thick. in	Carbon/Teflon gm	Carbon/Teflon gm/cc	Anode Ahrs	SO_2 Ahrs	C/SO_2*	Li/SO_2	Peak Voltage Volts	Time to 2V Hours	Venting Before 10 Hrs.	Vent Temp. of
1	0	538	DR169	0.036	9.16	0.341	9.90	10.66	1.24	0.93	2.50	2.3		
			DR171	0.036	9.16	0.341	10.06	10.62	1.24	0.95	2.52	2.7		
			DR174	0.036	9.73	0.362	10.53	10.59	1.32	0.99	2.51	2.45		
2	0	580	DR175	0.034	9.45	0.345	10.84	10.52	1.29	1.03	2.51	2.7		
			DR178	0.033	9.48	0.357	11.00	10.59	1.29	1.04	2.52	2.2		
			DR180	0.033	9.33	0.352	11.23	10.62	1.27	1.06	2.50	2.4		
3	0	631	DR181	0.029	9.88	0.389	12.25	10.57	1.35	1.16	2.58	2.45		
			DR183	0.028	9.78	0.400	12.91	10.64	1.32	1.21	2.53	2.2		
			DR185	0.028	9.43	0.384	13.03	10.61	1.28	1.23	2.50	2.5		
4	10	580	DR187	0.032	9.53	0.370	8.03	10.62	1.29	0.75	2.49	2.3		
			DR189	0.033	9.63	0.363	9.44	10.57	1.31	0.89	2.48	2.4	Yes	60
			DR190	0.034	9.43	0.345	9.41	10.42	1.30	0.90	2.51	2.45		
5	10	631	DR192	0.028	9.43	0.385	9.13	10.66	1.27	0.86	2.50	2.5	Yes	50
			DR194	0.028	9.73	0.397	9.62	10.68	1.31	0.90	2.50	2.7	Yes	58
			DR195	0.028	9.53	0.388	9.69	10.67	1.29	0.91	2.52	2.6	Yes	66
6	10	704	DR196	0.025	9.34	0.383	10.00	10.61	1.27	0.94	2.50	2.4		
			DR197	0.025	9.04	0.371	9.40	10.64	1.22	0.88	2.60	2.3		
			DR198	0.026	10.04	0.396	10.04	10.48	1.38	0.96	2.46	2.4		

* Based on 1.44 Ahr/g mix theoretical.

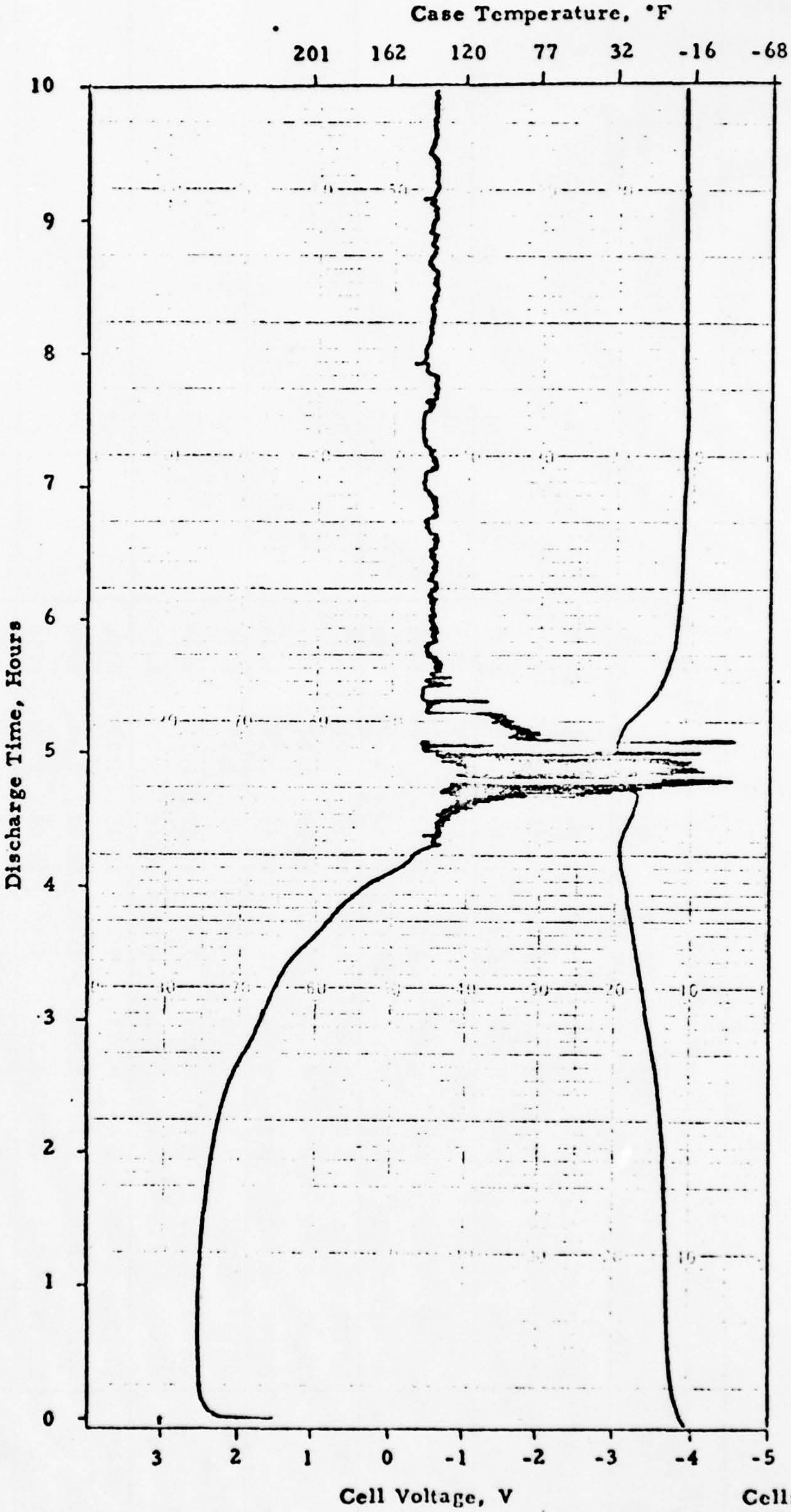


Figure 12. Performance/Safety Tests

Cell: DR175
Build: 8
Load: 2A
Temp: -20°F

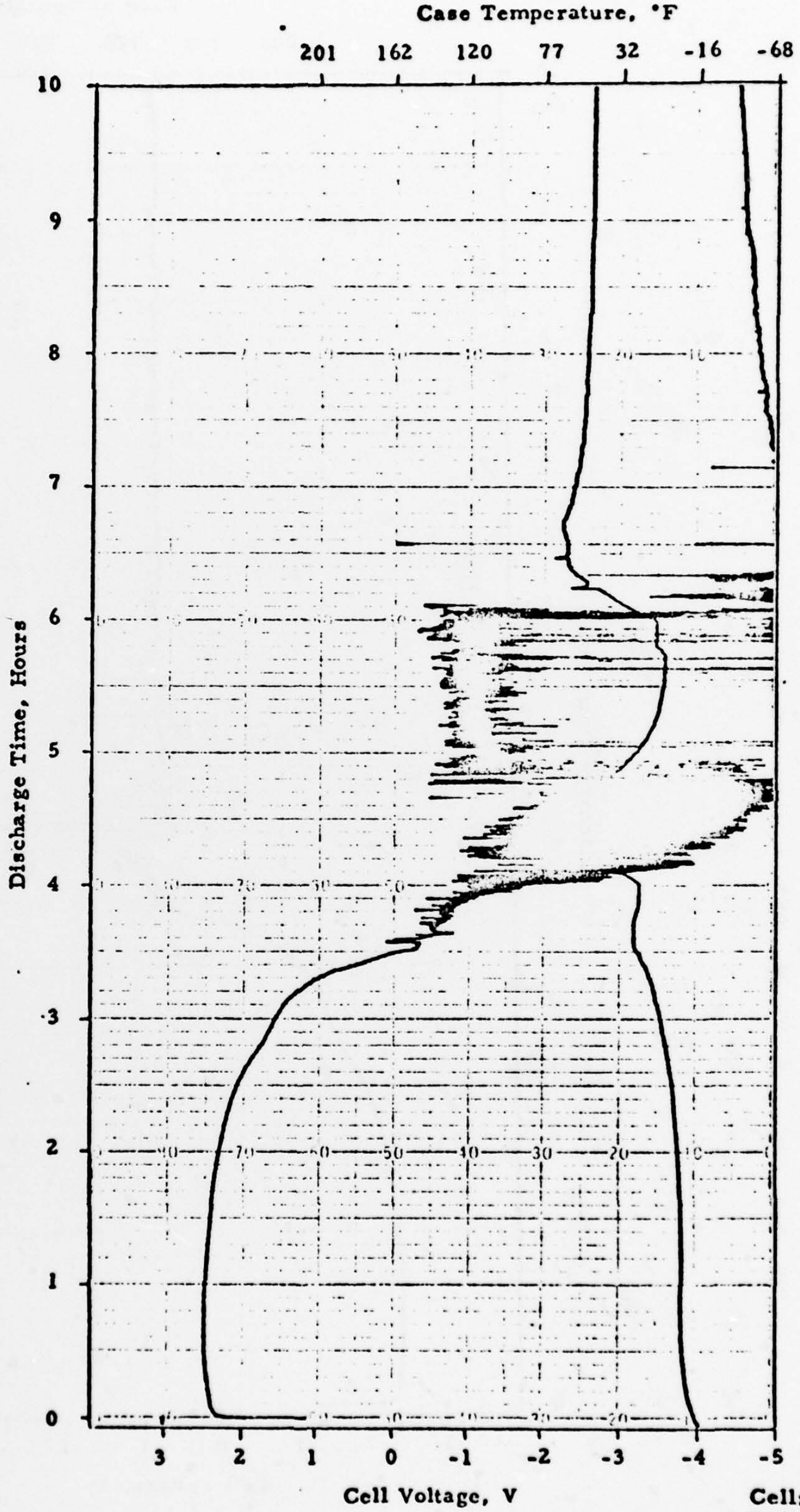
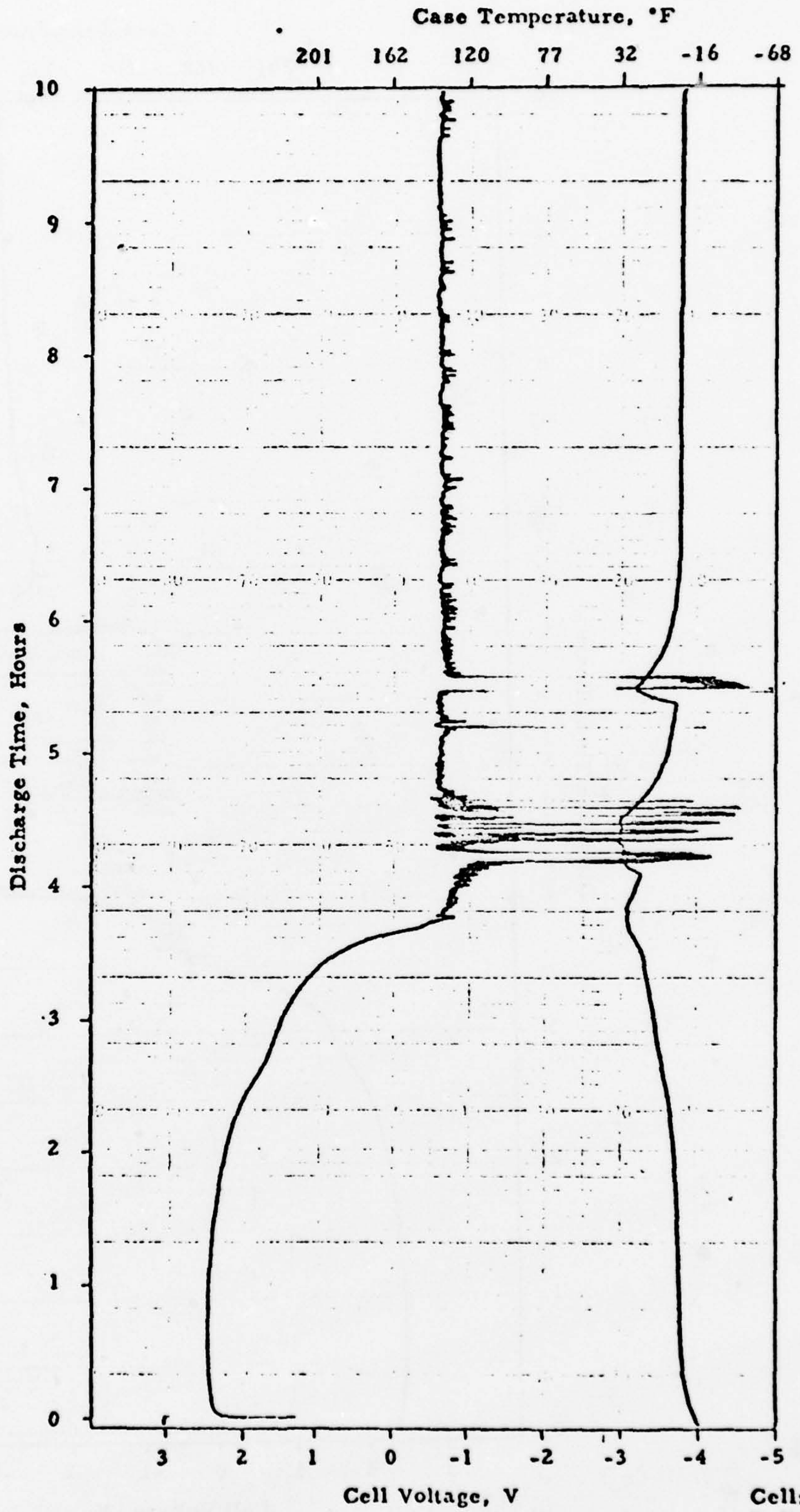


Figure 13. Performance/Safety Tests

Cell: DR195
Build: 8
Load: 2A
Temp: -20°F



Cell: DR196
Build: 8
Load: 2A
Temp: -20°F

Figure 14. Performance/Safety Tests

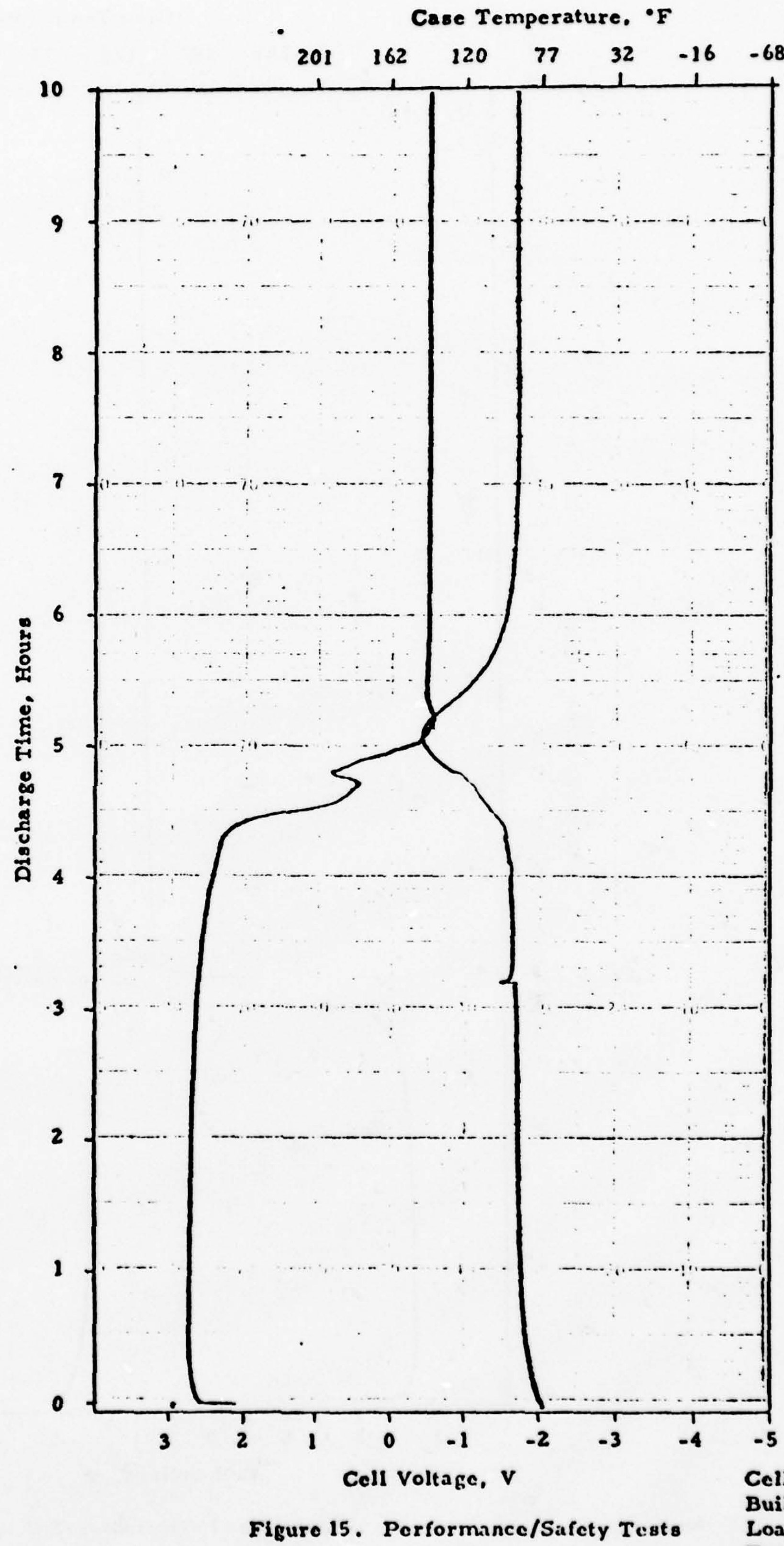


Figure 15. Performance/Safety Tests

Cell: DR186
Build: 8
Load: 2A
Temp: RT

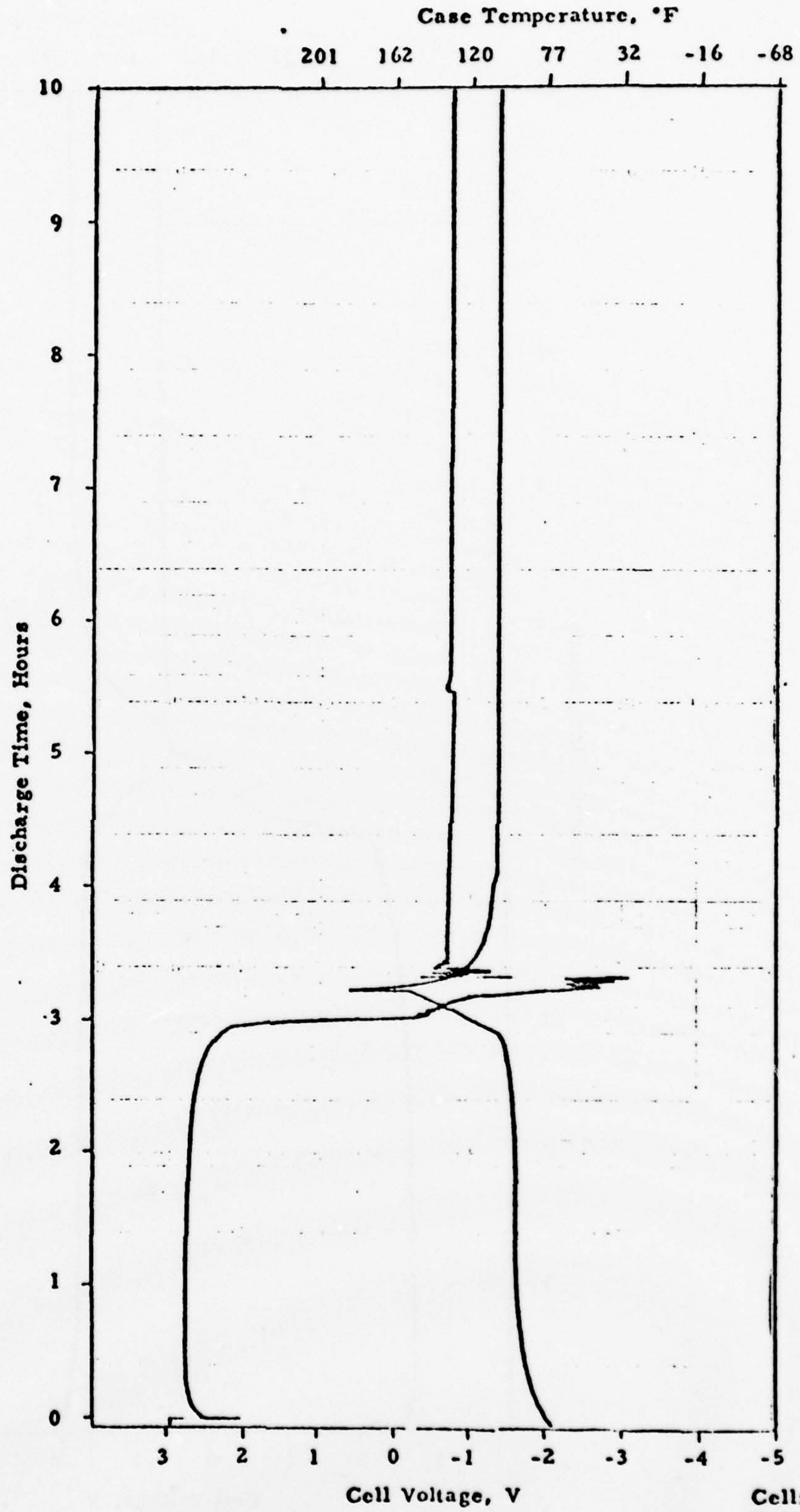


Figure 16. Performance/Safety Tests

Cell: DR188
Build: 8
Load: 2A
Temp: RT

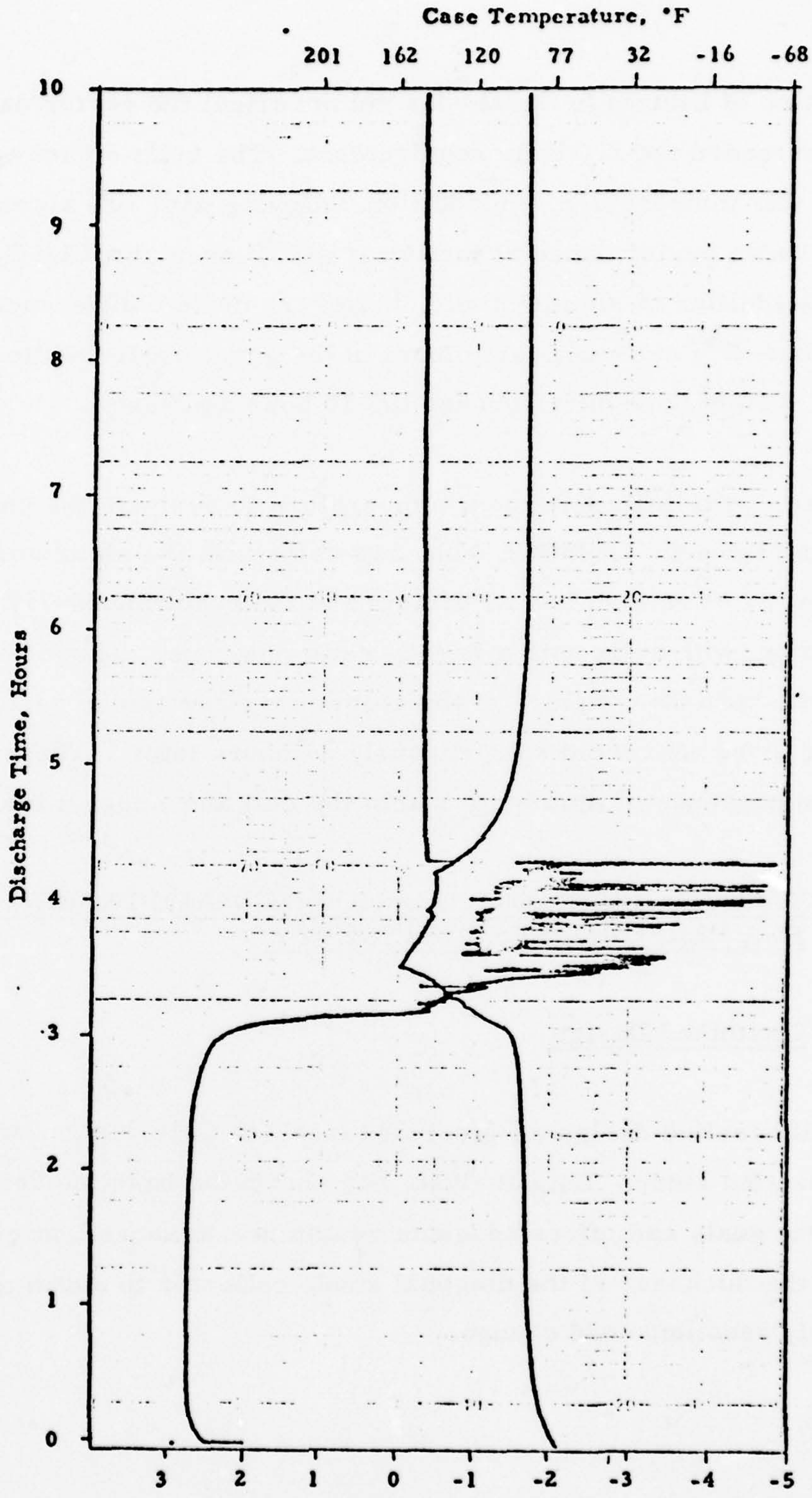


Figure 17. Performance/Safety Tests

Cell: DR 193
Build: 8
Load: 2A
Temp: RT

The variation of lithium in the anodes did not affect the performance as all cells at -20°F exceeded the 2.0 hour requirement. The cells do not appear to be lithium limited at this temperature. In addition, alloying with 10% aluminum does not appear to cause performance reduction at -20°F even at a Li/SO_2 ratio as low as 0.75. The addition of aluminum did, however, make a difference in the safety tests. Four of nine -20°F cells with aluminum in the anode vented while the nine without aluminum showed no venting through the 10 hour discharge.

Several cells were tested at room temperature to evaluate the performance and the results are shown in Table XII. The two cells with the aluminum alloy that were low in capacity were also low in lithium and the resulting 68-75% lithium efficiency was consistent with cells with a Li/SO_2 ratio near one. These limited tests further indicated the hazardous nature of the aluminum alloy as one vented during the discharge and a second vented spontaneously 24 hours later. These safety results make suspect the presence of aluminum within the cell and suggest further work.

d. TASK IV - CHARACTERIZATION OF "SAFE DESIGN" CELL FOR PERFORMANCE AND SAFETY

(1) Optimized Design

The overall baseline design as described in a.(1)-Cell Design, was retained for the characterization study. Data analysis had shown the baseline design attains the performance goals and offers adequate resistance to abuse test conditions. A reduction of the thickness of the diagonal anode collector to aid in the cell manufacture was the only recommended change.

Cathode

Data analysis of the cathode optimization, b.(3)-Test Results, indicated the best performing cathodes were those of highest carbon/Teflon weight irrespective of cathode density,

Table XII

TASK III - Li/SO_2 RATIO EVALUATION TEST RESULTS

Load: 2A Constant Current

Temp: Room

Build Data								Test Results			
Group	Cell No.	Al, %	Surface Area, cm^2	Carbon/ Teflon, gm	SO_2, Ahrs	C/SO_2*	Li/SO_2	Peak Voltage, V	Time to 2 V, hrs	Vent in Ten hrs	Vent Temp., °F
2	DR179	0	580	9.33	10.62	1.27	1.04	2.71	3.9		
3	DR186	0	631	9.43	10.65	1.28	1.19	2.72	4.45		
4	DR188	10	580	8.75	10.68	1.18	0.75	2.78	3.0	Yes	186
5	DR193	10	631	9.28	10.68	1.25	0.86	2.77	3.1	**	
6	DR199	10	704	9.69	10.00	1.32	0.94	2.77	4.0		

* Based on 1.44 Ahr/g theoretical.

** Cell vented on standing at room temperature 24 hours after load was removed.

thickness and Teflon content. With an active cathode surface of 580 cm^2 for high rate capability, and a cathode thickness limited to 0.032" by the internal case diameter, an increased density was required to maximize the carbon/Teflon weight. Although several higher density groups were fabricated, achieving greater than 0.38 gm/cc was considered to be unsound for a production operation. Optimum for production was judged to be 0.35 gm/cc (9.0 gm of carbon/Teflon) or that of the baseline design.

Cathode Scale-up. The initial scale-up results as noted in section a. were not satisfactory in process control; especially for density, and cathode efficiency. The Ahr. capacity achieved at 2A and -20°F did not correlate with the development cathodes shown in Figure 10.

The low percentage of Teflon, required for performance, was difficult to process into the carbon uniformly without large quantities of water. This apparently reduced the quality of the mix from our large capacity mixer, which must limit the water content. We thus returned to our slurry process using somewhat larger and more concentrated batches to scale up the process. The slurry is filtered into a large cake before it is oven dried and micronized.

The capacity of the micronization process was increased by the use of a 10 cubic foot chopper type mixer. The larger micronizer produced acceptable mix when the chopper blades were modified to simulate the previously used low capacity laboratory blender. Micronization of up to 20 lbs. of carbon/Teflon mix was accomplished within minutes in this manner. It was noted that the storage of the larger quantities of micronized material would cause densification in both the mix and the milled material. Limiting the quantity per storage container and remicronizing when necessary has minimized this problem.

Continuous roll forming of the micronized carbon/Teflon mix was accomplished by hand feeding the mix onto the pre-slit grid as it passed through the rolls. The coated grid was cut to length, weighed, and measured as it emerged from the rolls.

Anode

A lithium thickness of 0.007" (toleranced from 0.0065 to 0.0080" by the supplier) was maintained throughout the development tests and was considered adequate for performance and safety within a Li/SO_2 ratio range of 0.9 to 1.1. For a nominal SO_2 content equivalent to 10.5 Ahr., the predicted theoretical lithium capacity for this material would range from 8.9 to 10.9 Ahr. If the electrolyte fill range could be minimized, the Li/SO_2 ratio would be held within the optimum range.

Anode Collector. The diagonal anode collector was maintained throughout the program to ensure lithium continuity during deep discharge. It was effective in providing high lithium efficiency and was retained even though it presents manufacturing problems. The main problem, shorting during the electrode wrapping process, was greatly minimized by reducing the nickel collector from 0.005" to 0.003" thick. This change was instituted following the baseline cell build and showed no voltage or capacity losses. The 0.003" thick diagonal anode collector then became the standard for "Safe Design" characterization cells.

Electrolyte

The SO_2 concentration was optimized at 68% in a previous contract (1) and was maintained through Builds 4 - 8. It continues to yield the design goals of 4 and 8 Ahr. at a 2A constant current discharge at -20°F and room temperature respectively.

Separator

One layer of Celgard between electrodes minimizes separator volume allowing cathode weight maximization for improved performance and safety. Although the thinness of one layer contributes to occasional shorting during the electrode wrapping process, this problem has been largely overcome by reducing the anode collector thickness and its advantages overshadow these manufacturing difficulties.

Table XIII

Task IV Construction Statistics

Sample Size: 250

Parameter	$\bar{x}$ Average	δ Standard Deviation	R Range
Cathode Wt (Carbon & Teflon) g	9.34	0.42	8.60 - 10.5
Anode Theoretical Capacity, Ahr	10.88	0.60	9.52 - 12.05
SO Theoretical Capacity, Ahr	10.51	0.09	10.30 - 10.69
Li/SO Ratio	1.04	-	0.93 - 1.12
(C & Tef)/SO Ratio*	1.28	-	1.14 - 1.46

* Based on 1.44 Ahr/g mix theoretical.

(2) Cell Fabrication

A total of 250 cells was manufactured for this build with 120 of these allocated for test and delivery for this contract. All raw materials were kept constant although there was no attempt to control them as single lots. The statistics for the measured parameters are shown in Table XIII. When compared to the similar statistics for the baseline cell, as shown in Table III, a significant increase in the standard deviation and range of all parameters was noted especially in the anode theoretical capacity. With relatively close control of the activation weights, the Li/SO_2 ratio nearly stayed within the desired 0.9 to 1.1 limits. The range of carbon weight larely increased in the positive direction would be beneficial for performance as noted in section a.(1). The lower end of the anode weight range could have a detrimental effect on capacity as up to 84% anode efficiency would be required to achieve the desired 8.0 Ahr. at 2A at room temperature.

(3) Test Results

Test Matrix

The tests were divided into four groups as follows:

I. Constant Current
   A. 2.0A
   B. 3.5A
   C. 5.0A

II. Constant current following 2 week storage at $160^{o}F$

III. Pulse (1 sec. duration)

	Pulse Load	Duty Cycle
A.	10.0A	4:1
B.	20.0A	9:1

IV. Short Circuit

All tests were run at three temperatures: -20°F, room temperature, and 130°F. Groups I through III were discharged to 20 Ahr. (approx. 200% of the theoretical SO_2 equivalent capacity) where practical. The duty cycle for pulsing was regulated to produce an average current of 2A. Due to equipment limitations, we were able to discharge only four cells at a time and chose to run the room temperature and 130°F cells togehter (2 of each) and three each of the -20°F for each current profile.

All cells were heat soaked at 130°F for a minimum of 2 days to equilibrate the cells and weed out leakers.

Test Procedure

The test setup remained similar to that described in a. (3)-Test Setup. Voltage and case temperatures were monitored during the controlled discharges while current and case temperatures were monitored during the short circuit tests. Suspected vent occurrences were confirmed by visual examination following the test.

Performance Results. The constant current test results for unstored cells are shown in Table XIV. A plot of the capacity vs temperature for the varying discharge currents is shown in Figure 18. Representative graphs are shown in Figures 19 - 27. The performance data shows essentially no capacity difference between 2.0 and 3.5A, probably due to the added heating effect at the higher current. The same is true for 5.0A, -20°F test cells which yielded equivalent capacity to the 2.0A and 3.5A cells but at the two higher temperature points, considerable losses were noted. Cells discharged at 130°F showed no capacity loss as compared to the room temperature cells at the same current.

The discharge data following 2 weeks of storage at 165°F, Table XV, shows improvement in the room temperature capacity at 2A but a loss at -20°F and 130°F.

Table XIV

Constant Current Discharge Results for Unstored Cells

Cell No.	Temp. (^{o}F)	Current (A)	Peak (V)	Time (Hr) To 2V	Capacity To 2.0V (Ahr)	Time To Vent (min.)	Vent Temp. (^{o}F)
DR320	-20	2A	2.50	2.0	4.0	-	-
329			2.48	2.0	4.0	-	-
327			2.50	2.5	5.0	-	-
328	RT	2A	2.80	3.7	7.4	4.3	232
330			2.70	3.9	7.8	-	-
321	130	2A	2.79	3.5	7.0	-	-
323			2.79	4.1	8.2	-	-
312	-20	3,5	2.47	1.33	4,7	2,7	97
313			2.43	1,10	3.9	2.9	162
311			2.43	1.20	4,2	-	-
325	RT	3.5	2.75	2.22	7,8	3,2	194
326			2.62	2,08	7.3	2.6	190
317	130	3.5	2.78	2.17	7.6	3,2	198
318			2,71	2.17	7.6	3,2	190
307	-20	5,0	2.40	.90	4.5	-	-
306			2.40	.82	4.1	1,6	99
308			2,40	.75	3.8	1,8	73
316	RT	5.0	2.65	1.27	6.4	1,7	178
319			2.52	1.15	5,8	1.6	205
315	130	5,0	2.69	1.27	6.4	1,4	190
314			2.72	1,13	5.7	1,5	186

Table XV

Constant Current Discharge Results Following 2 Weeks at 165°F

Cell No.	Temp. (°F)	Current (A)	Peak (V)	Time (Hr) To 2V	Capacity To 2.0V (Ahr)	Time To Vent (min.)	Vent Temp. (°F)
DR292	-20	2.0	2.32	1.3	2.6	-	-
291			2.13	1.0	2.0	-	-
293			2.22	1.5	3.0	-	-
298	RT		2.78	4.2	8.4	-	-
297			2.78	3.2	6.4	-	-
294	130		2.79	3.8	7.6	-	-

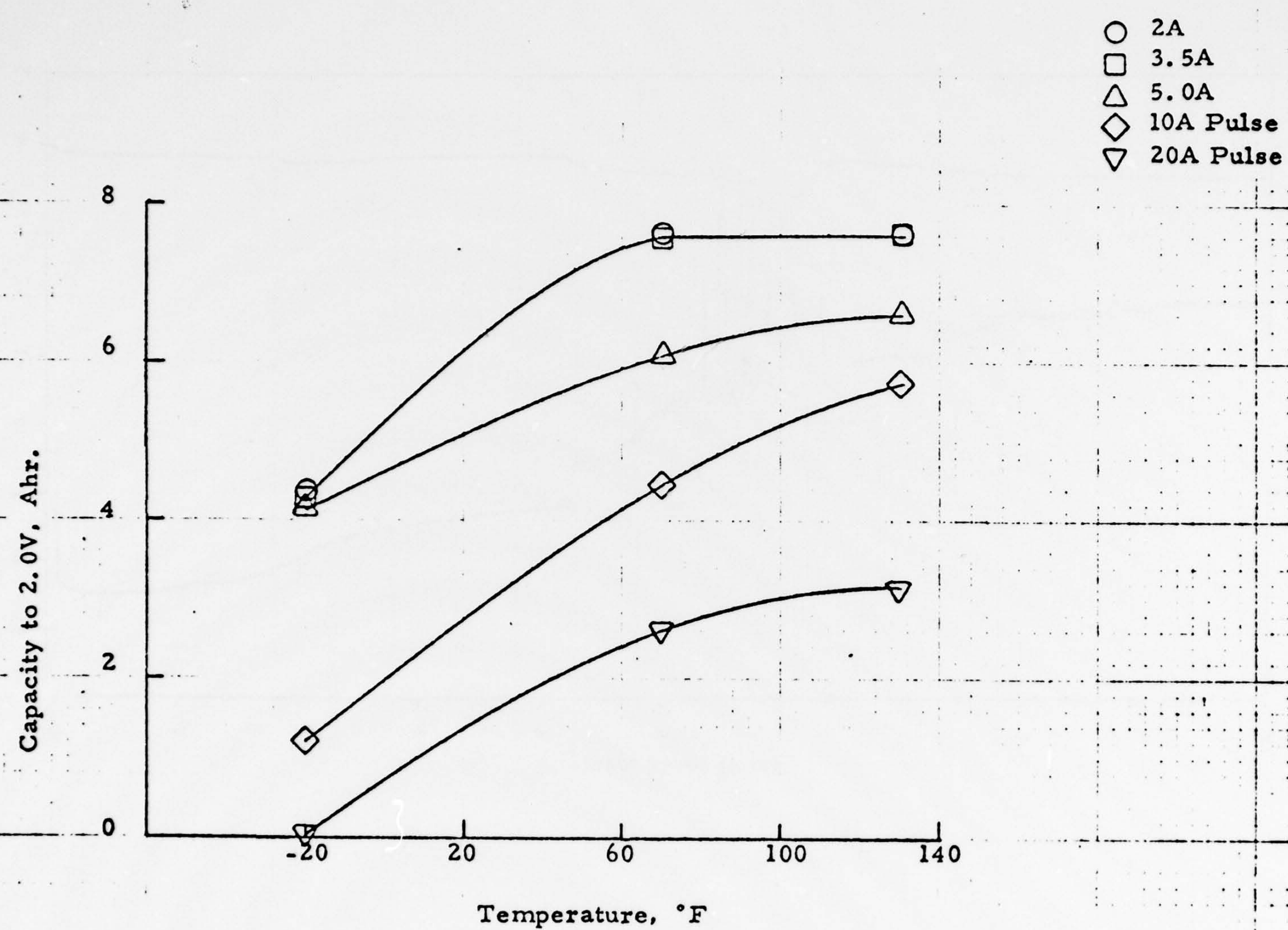


Figure 18: Capacity As a Function of Temperature and Rate

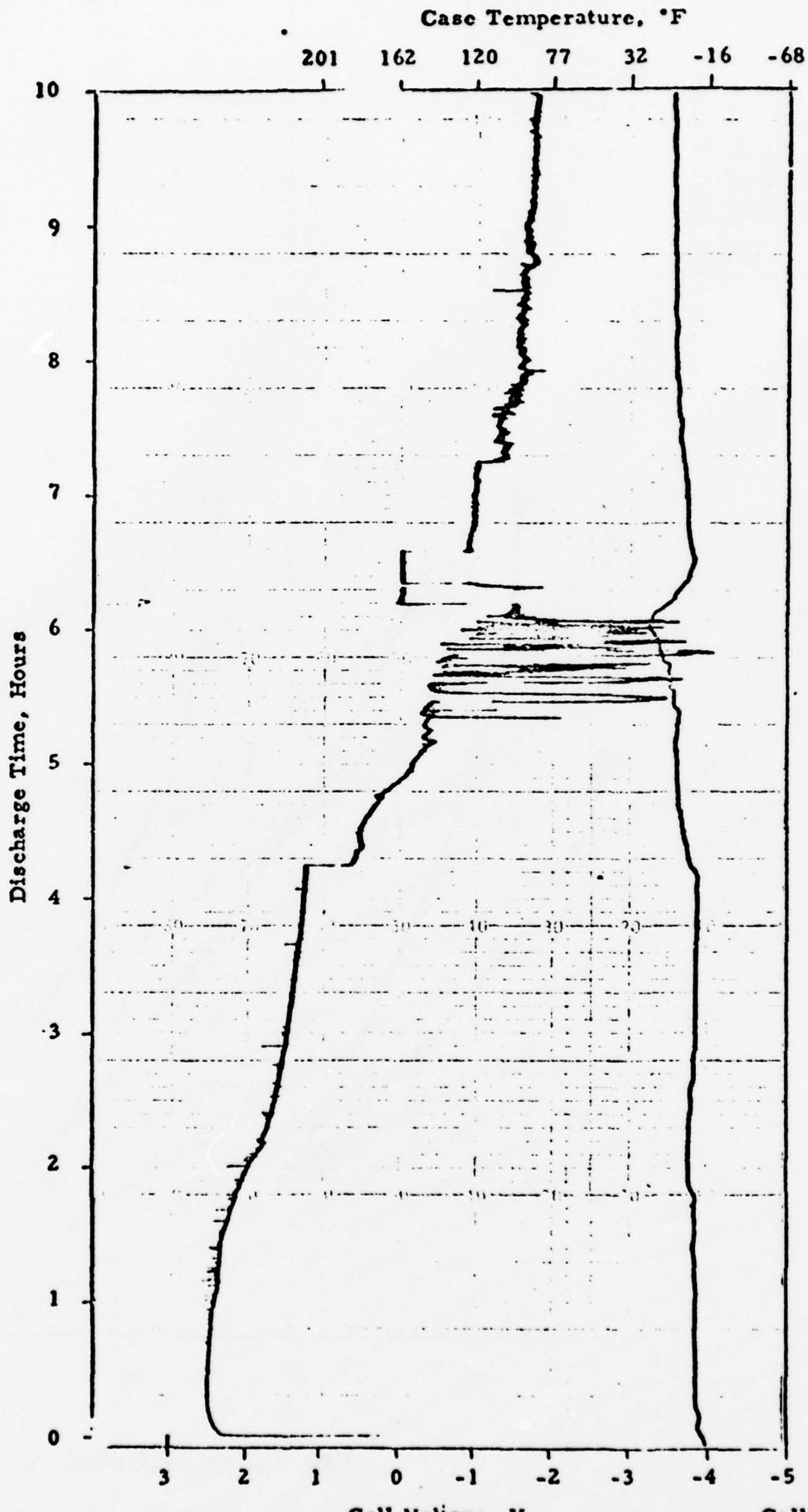
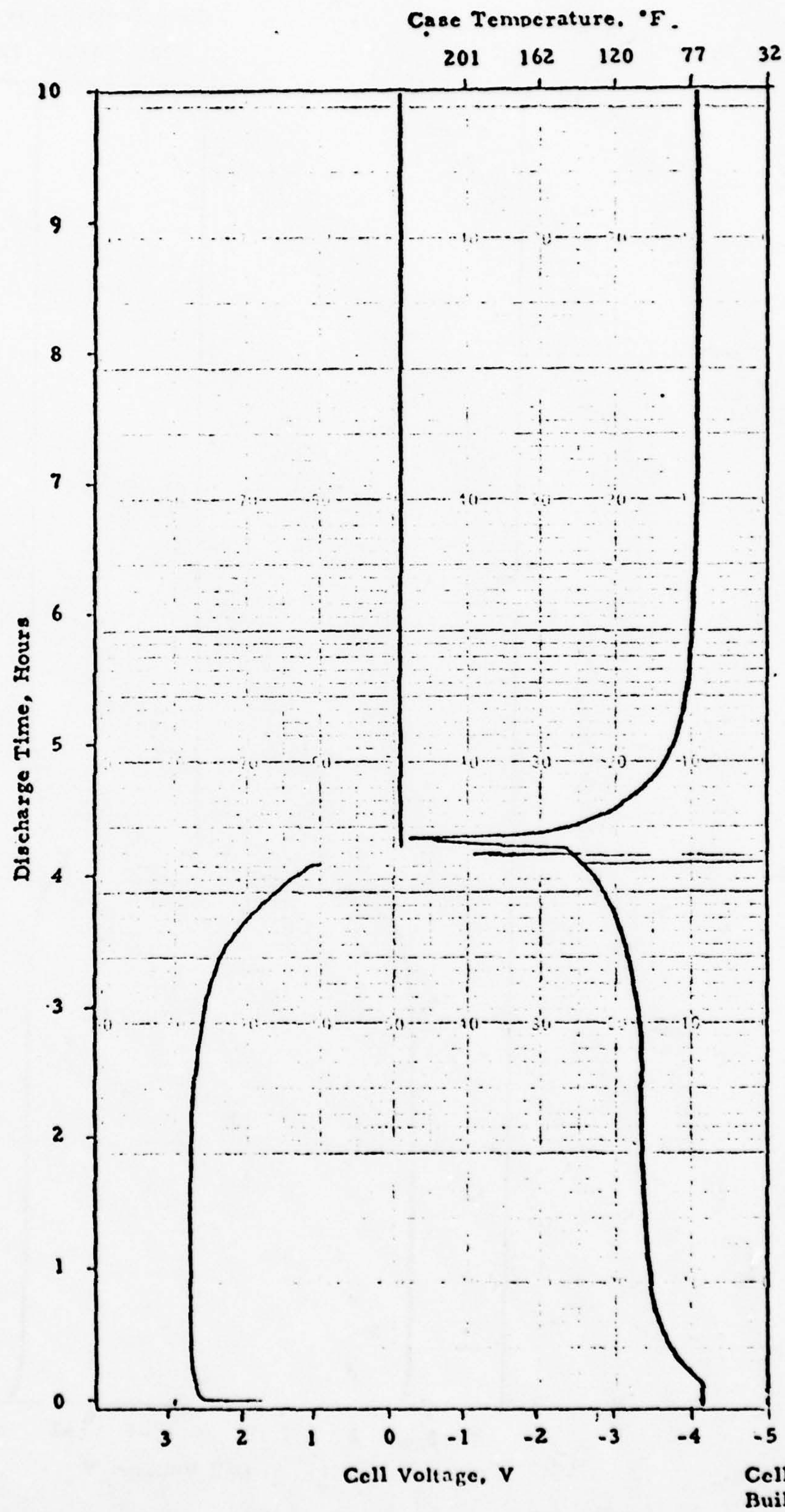


Figure 19. Performance/Safety Tests

Cell: DR320
Build: 9
Load: 2.0A
Temp: -20°F



Cell: DR328
Build: 9
Load: 2.0A
Temp: RT

Figure 20. Performance/Safety Tests

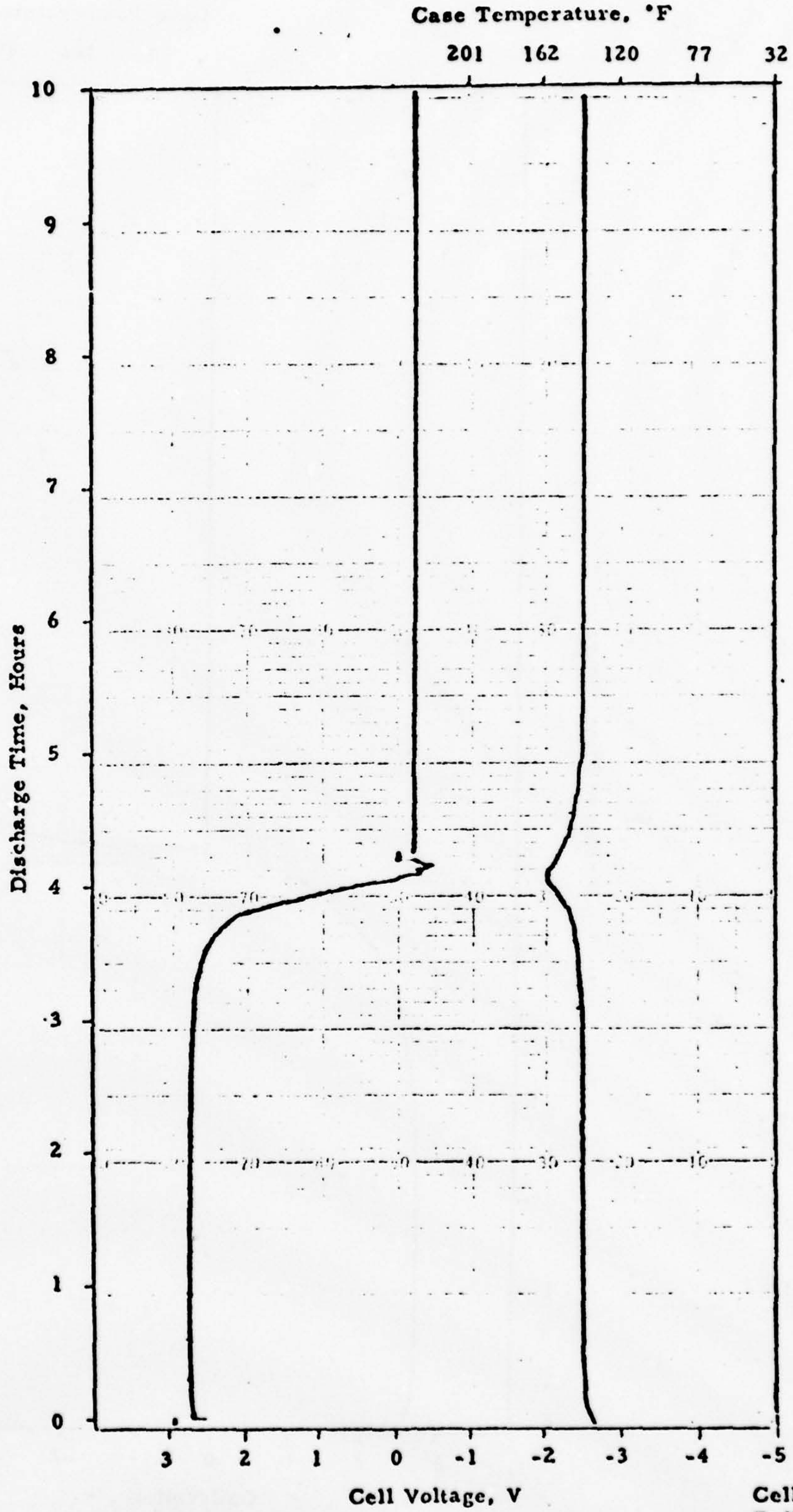


Figure 21. Performance/Safety Tests

Cell: DR321
Build: 9
Load: 2.0A
Temp: 130°F

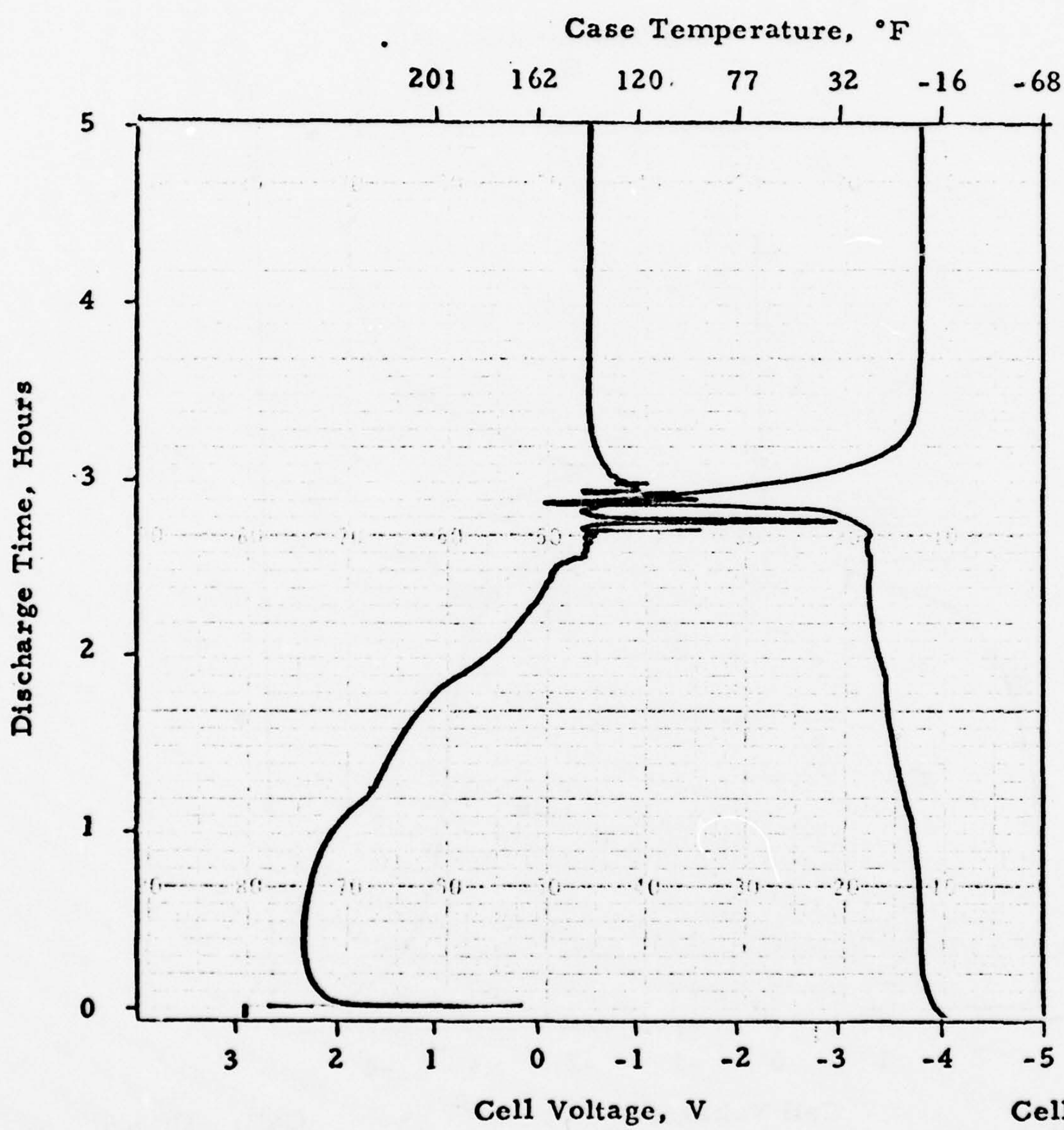


Figure 22. Performance/Safety Tests

Cell: DR313
Build: 9
Load: 3.5A
Temp: -20°F

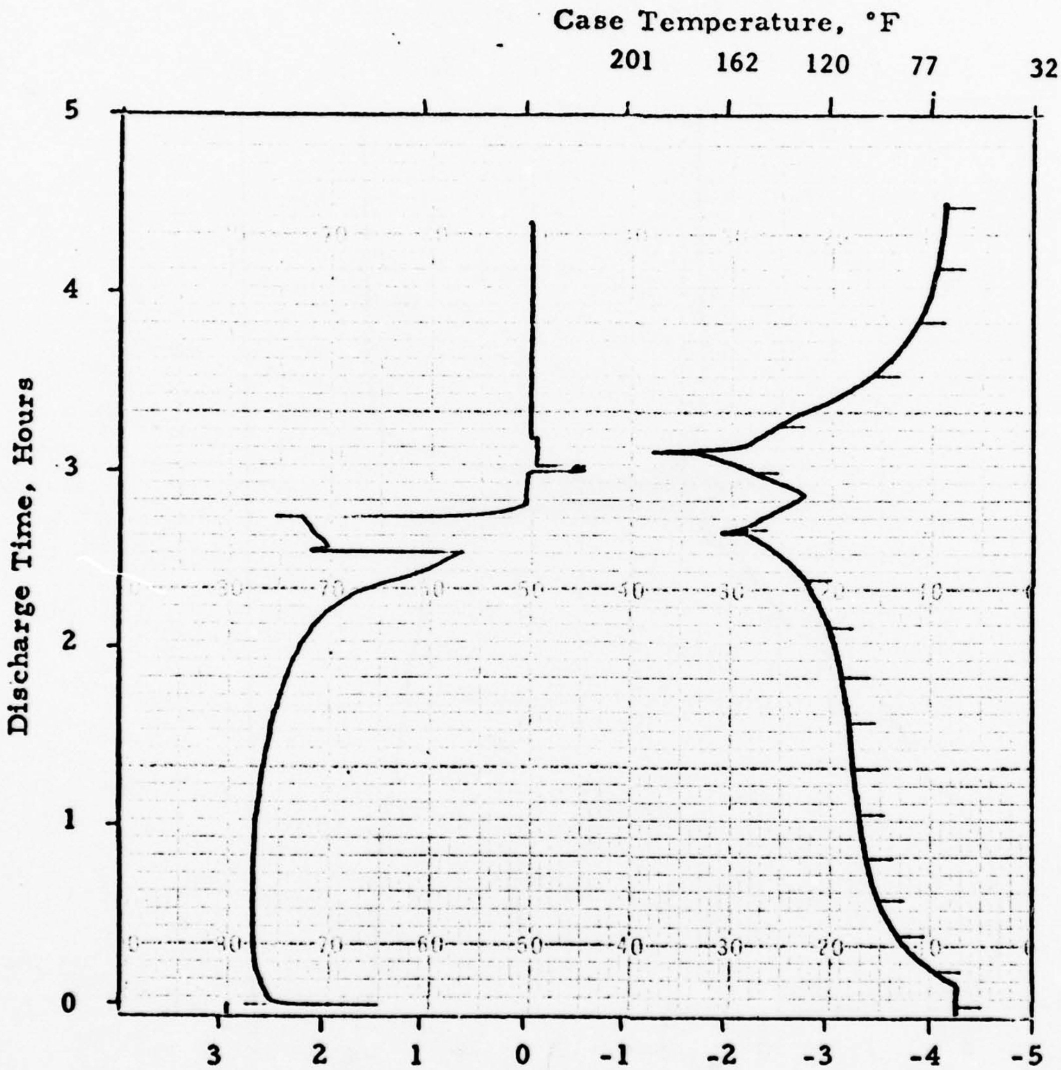


Figure 23. Performance/Safety Tests

Cell: DR325
Build: 9
Load: 3.5A
Temp: RT

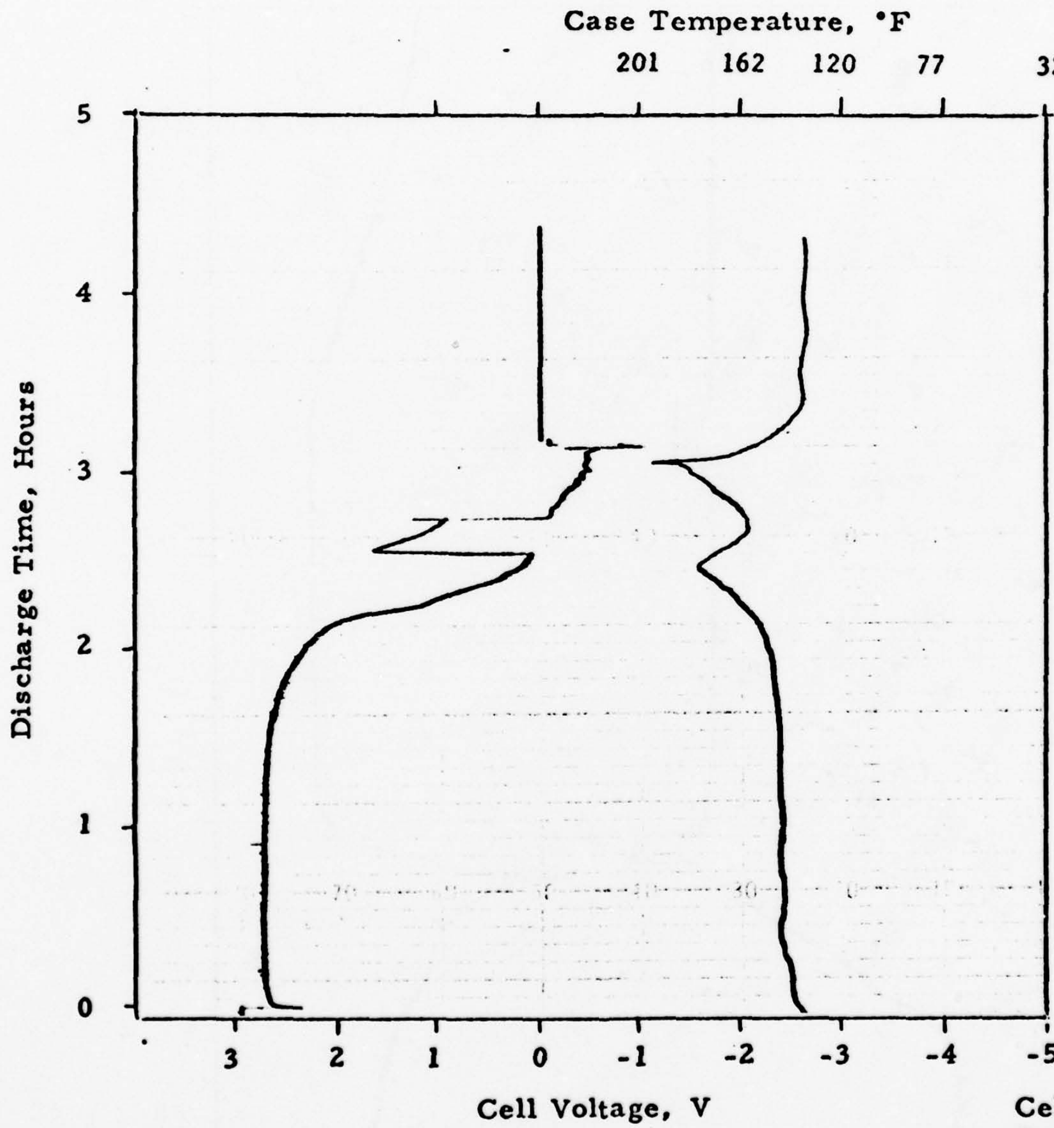


Figure 24. Performance/Safety Tests

Cell: DR317
Build: 9
Load: 3.5A
Temp: 130°F

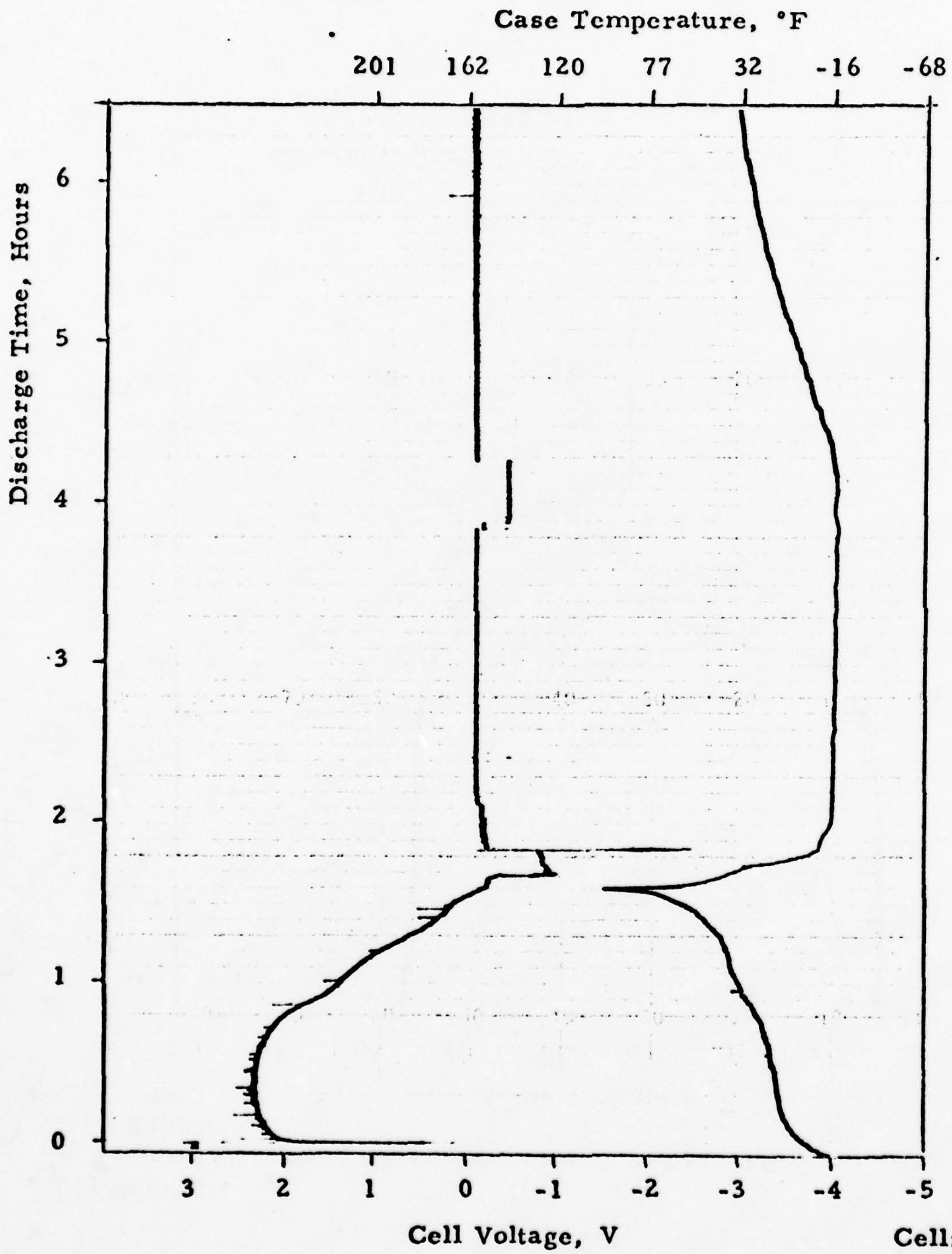


Figure 25. Performance/Safety Tests

Cell: DR306
Build: 9
Load: 5.0A
Temp: -20°F

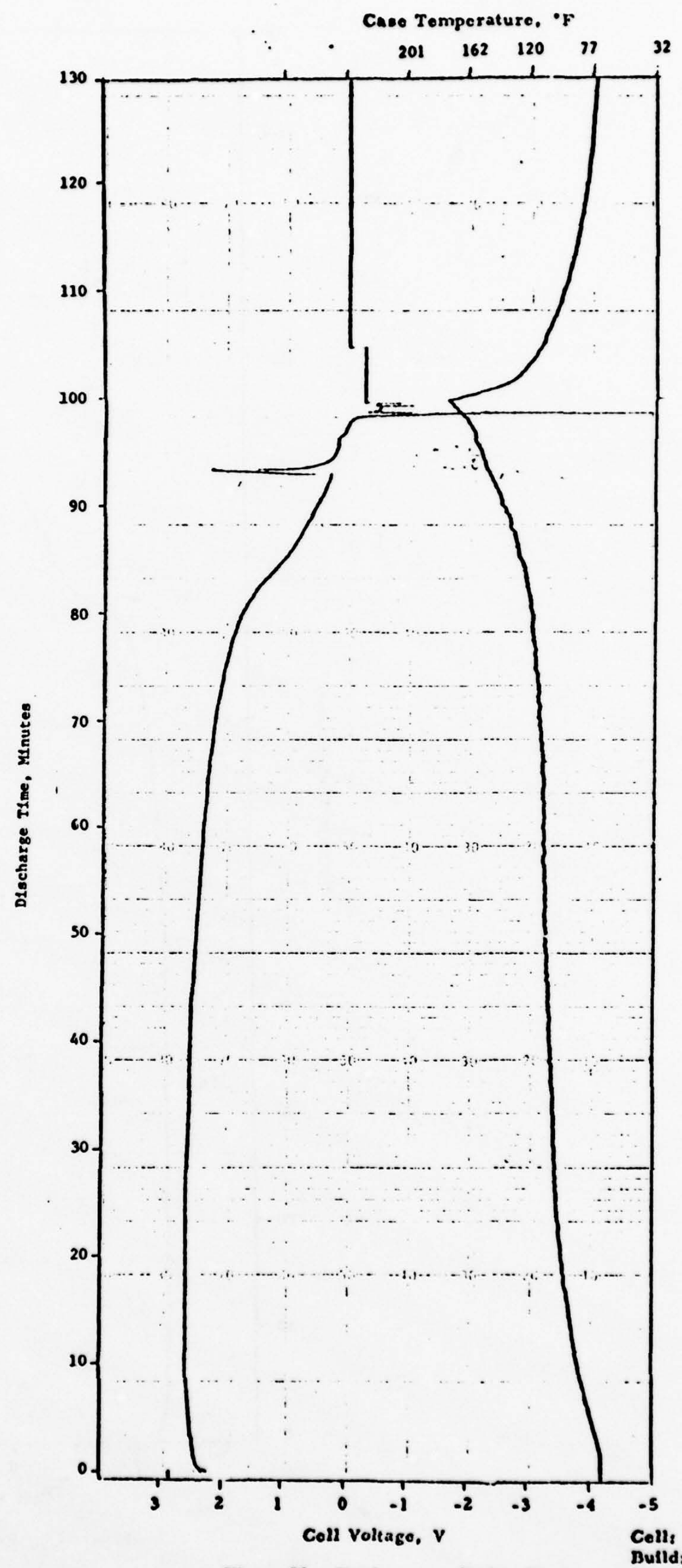


Figure 26. Performance/Safety Tests

Cell: DR316
Build: 9
Load: 5A
Temp: RT

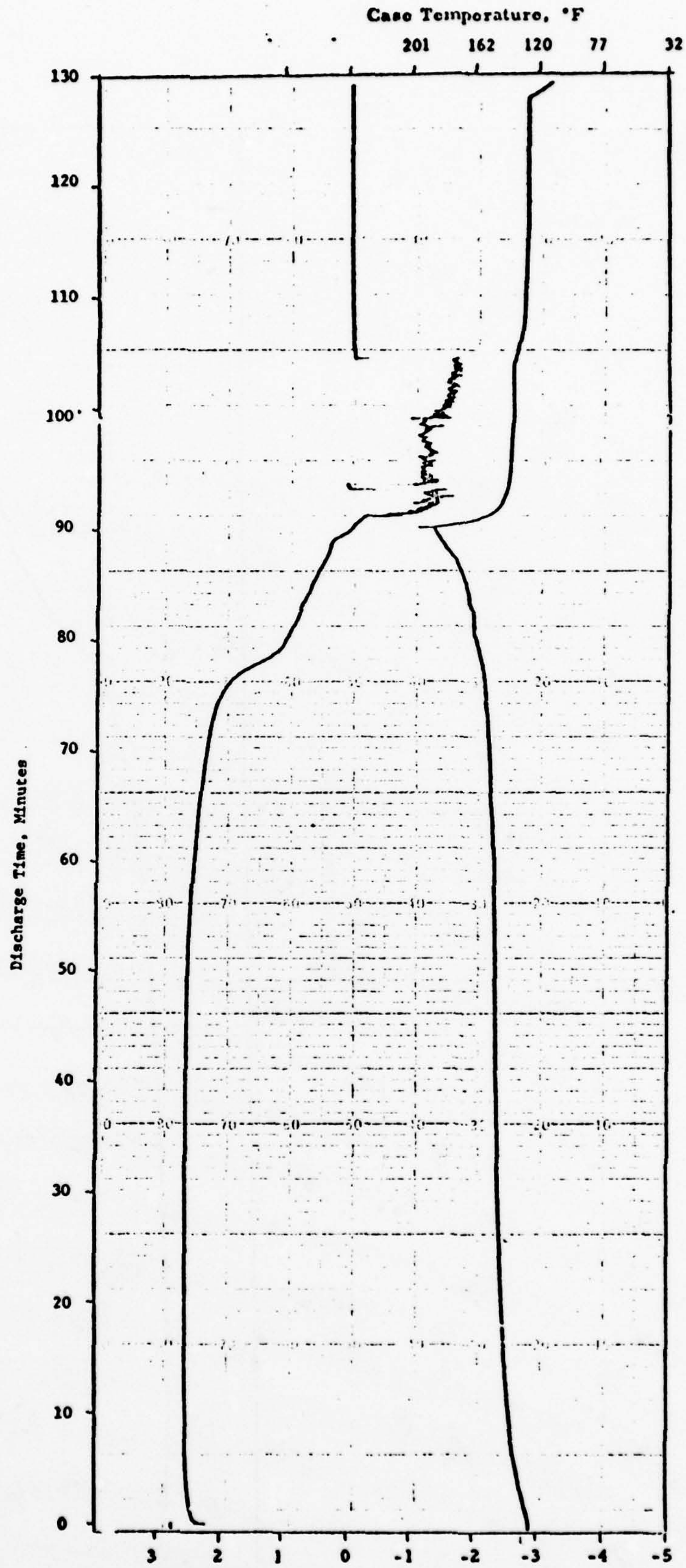


Figure 27. Performance/Safety Tests

Cell: DR315
Build: 9
Load: 5A
Temp: 130°F

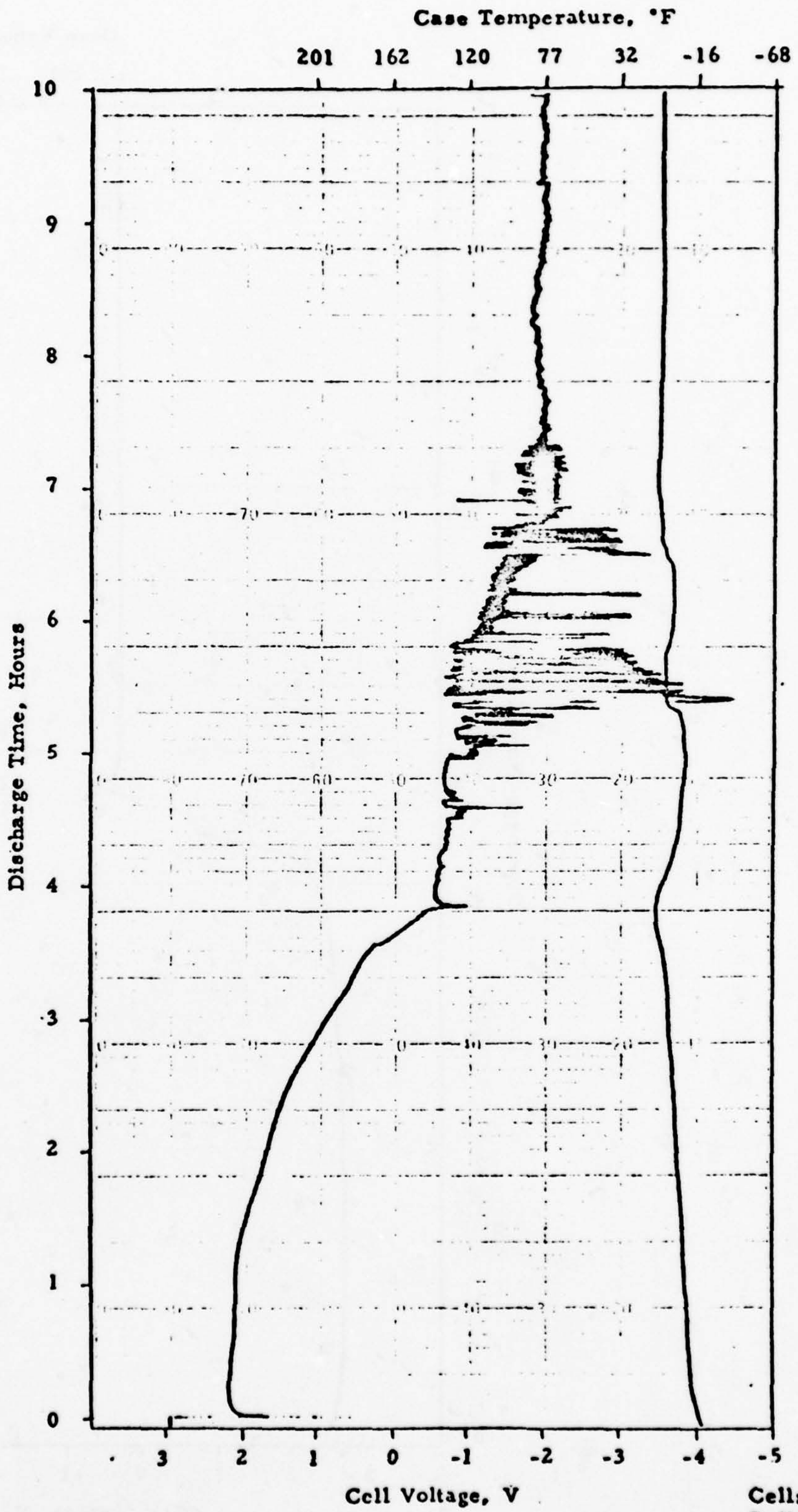


Figure 28. Performance/Safety Tests

Cell: DR293
Build: 9
Load: 2A
Temp: -20°F

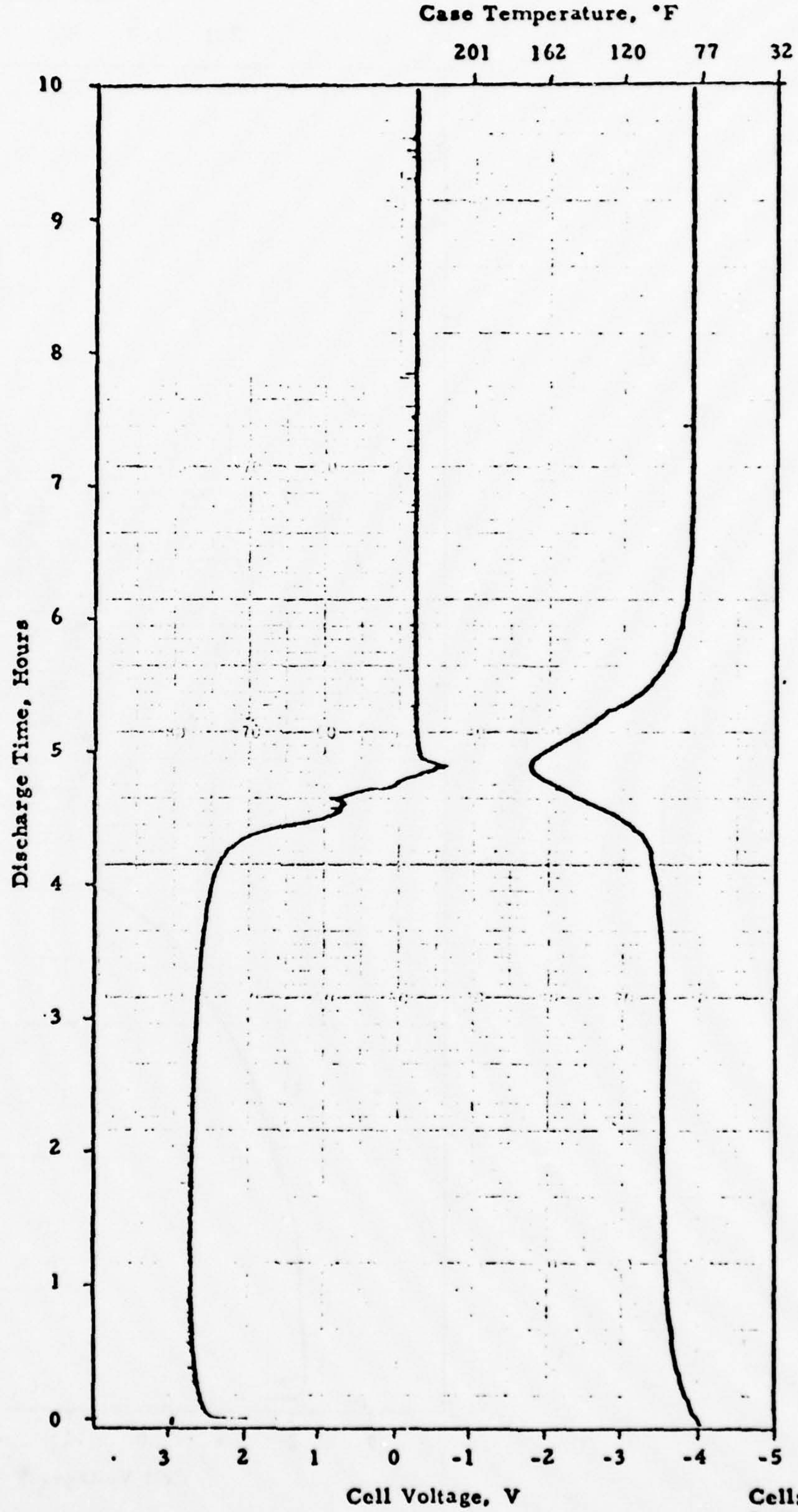


Figure 29. Performance/Safety Tests

Cell: DR298
Build: 9
Load: 2A
Temp: RT

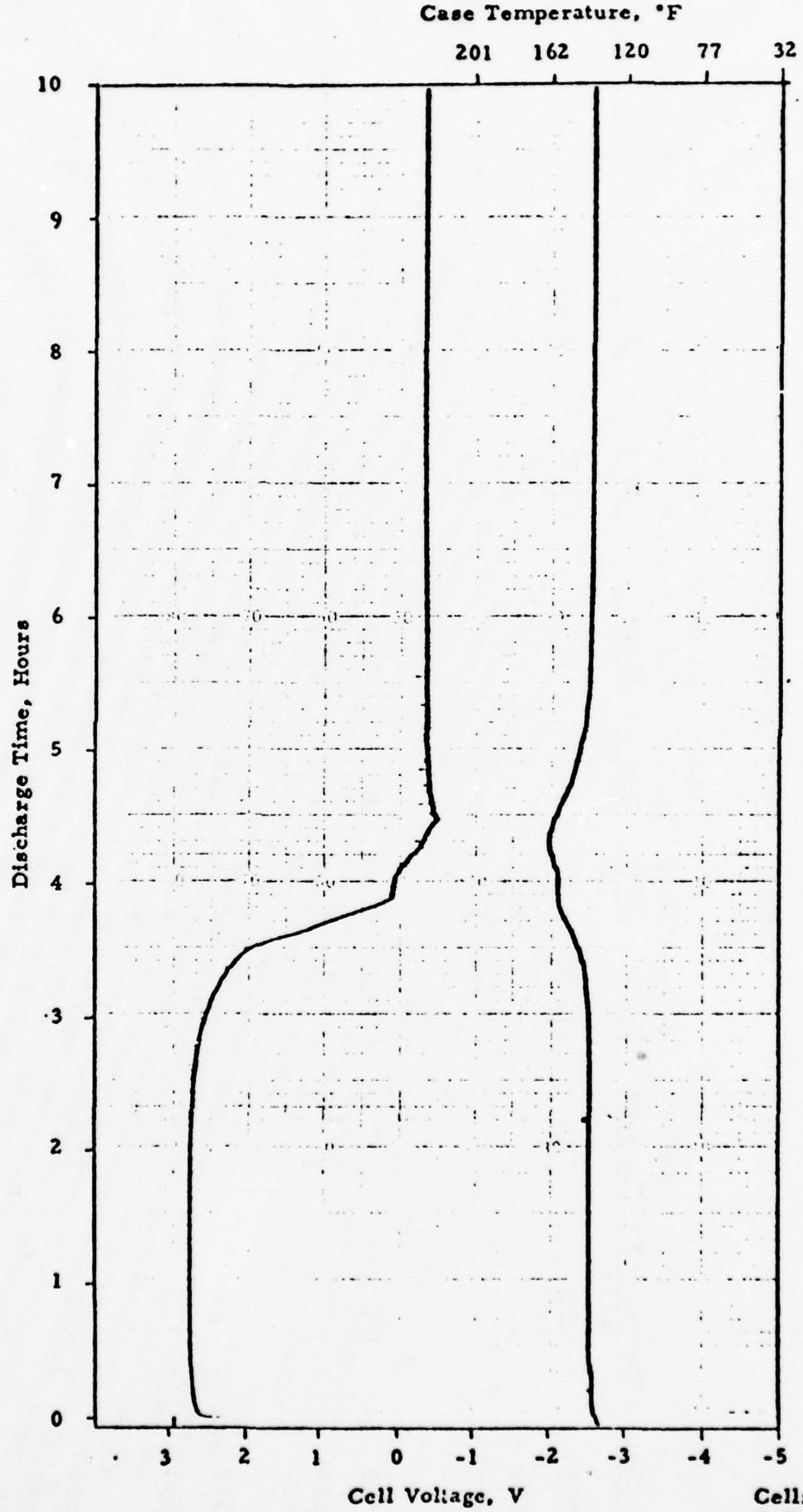


Figure 30. Performance/Safety Tests

Cell: DR294
Build: 9
Load: 2A
Temp: 130°F

Table XVI

PULSE DISCHARGE RESULTS

Cell No.	Temp. (°F)	Pulse Current	Duty Cycle	Peak (V)	Time to 2V (Hr.)	Capacity to 2.0V (Ahr)	Time to to 1.0V (Hr)	Capacity to 1.0V (Ahr)	Time to Vent (Hr)	Vent Temp. (°F)
DR305	120	10A	4:1	2.01	.7	1.3	2.2	4.4	4.4	37
309				2.08	.7	1.3	2.3	4.6	4.5	95
310				2.00	.5	1.0	2.0	4.0	4.1	209
335	RT			2.49	2.3	4.5	2.8	5.5	3.8	232
334				2.43	2.2	4.4	2.8	5.5	3.8	190
333	130			2.49	2.8	5.5	3.4	6.8	-	-
332				2.46	3.0	6.0	4.1	8.2	4.7	192
304	-20	20A	9:1	1.62	-		1.6	3.2	4.1	134
302				1.60	-		1.5	3.0	4.3	55
303				1.60	-		1.3	2.7	4.2	69
339	RT			2.10	1.3	2.6	2.7	5.3	3.1	205
340				2.12	1.4	2.7	2.6	5.2	3.1	232
338	130			2.05	1.6	3.2	2.9	5.8	4.7	198
337				2.05	1.5	3.0	2.9	5.8	4.6	202

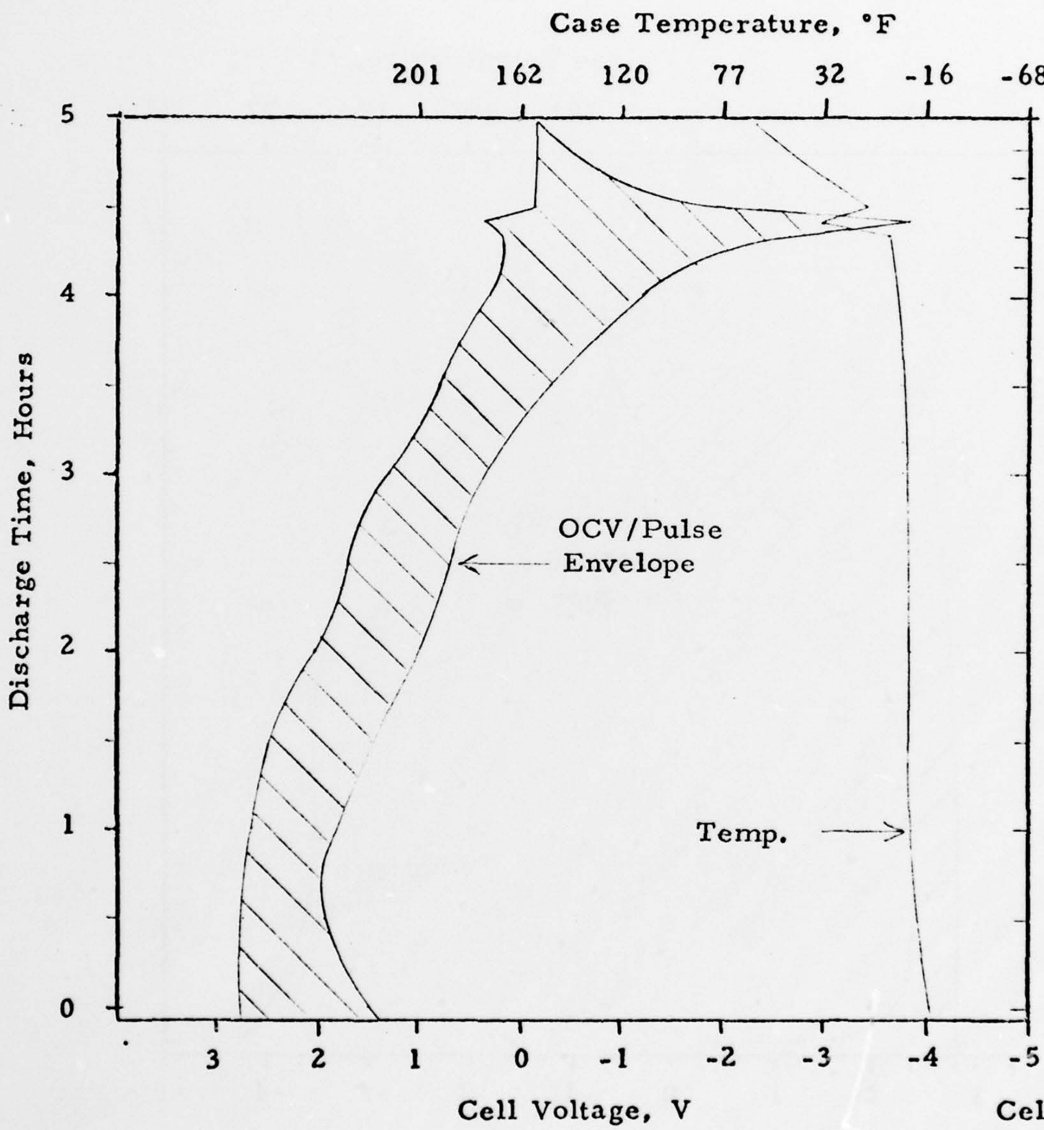


Figure 31. Performance/Safety Tests

Cell: DR305
Build: 9
Load: 10A
Temp: $-20^{\circ}F$

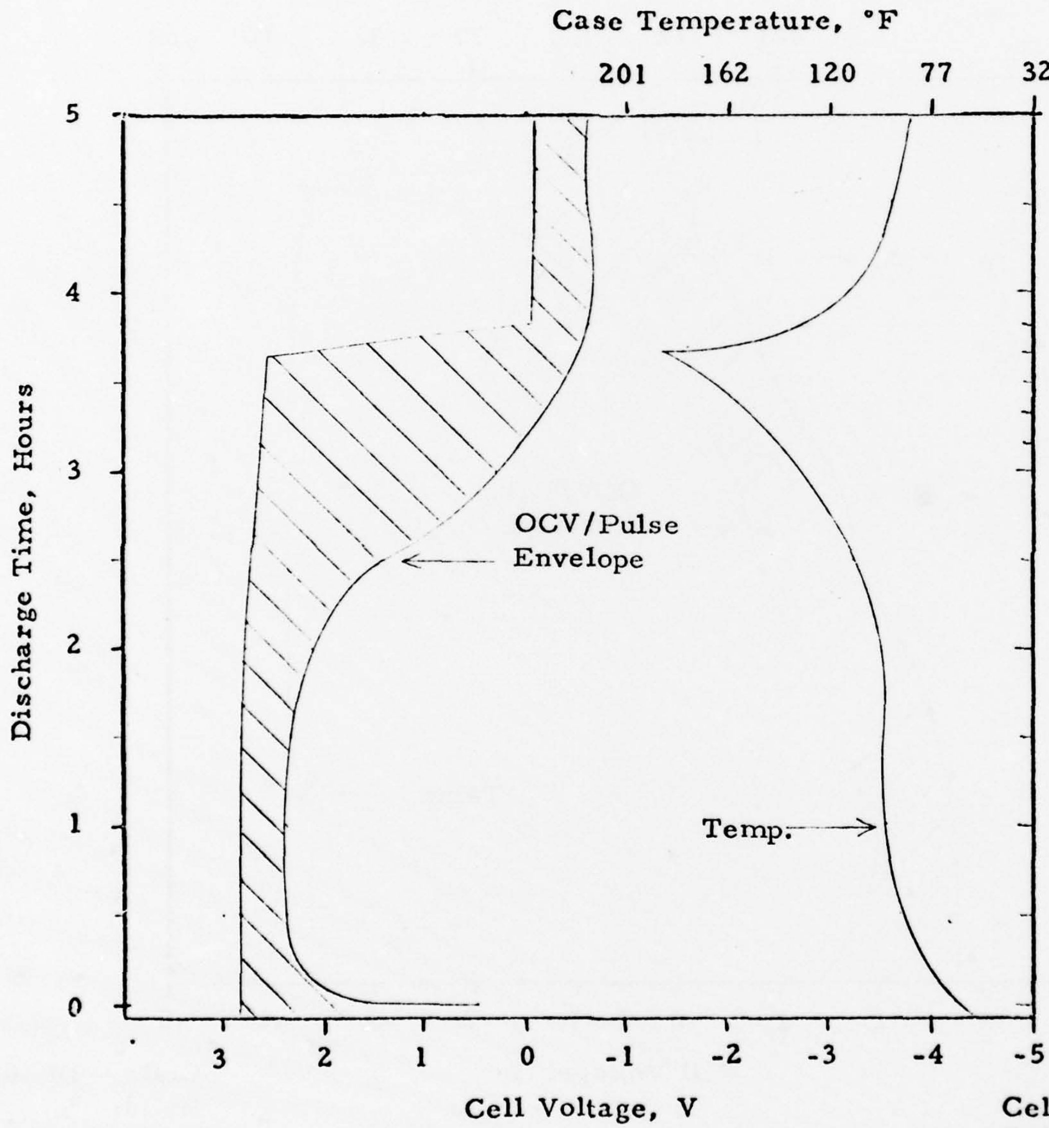
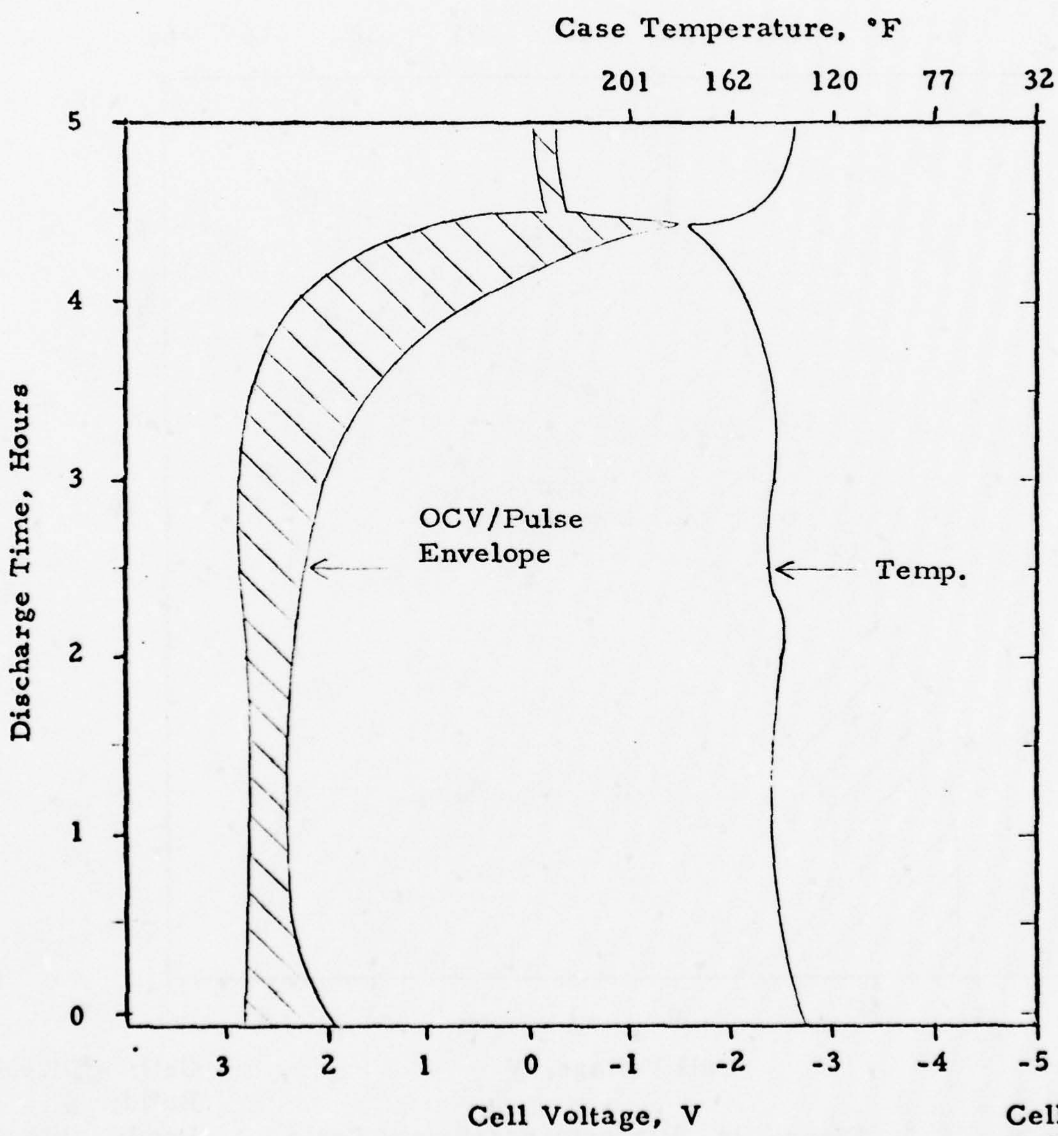


Figure 32. Performance/Safety Tests

Cell: DR334
Build: 9
Load: 10A
Temp: RT



Cell: DR332
Build: 9
Load: 10A
Temp: $130^{o}F$

Figure 33. Performance/Safety Tests

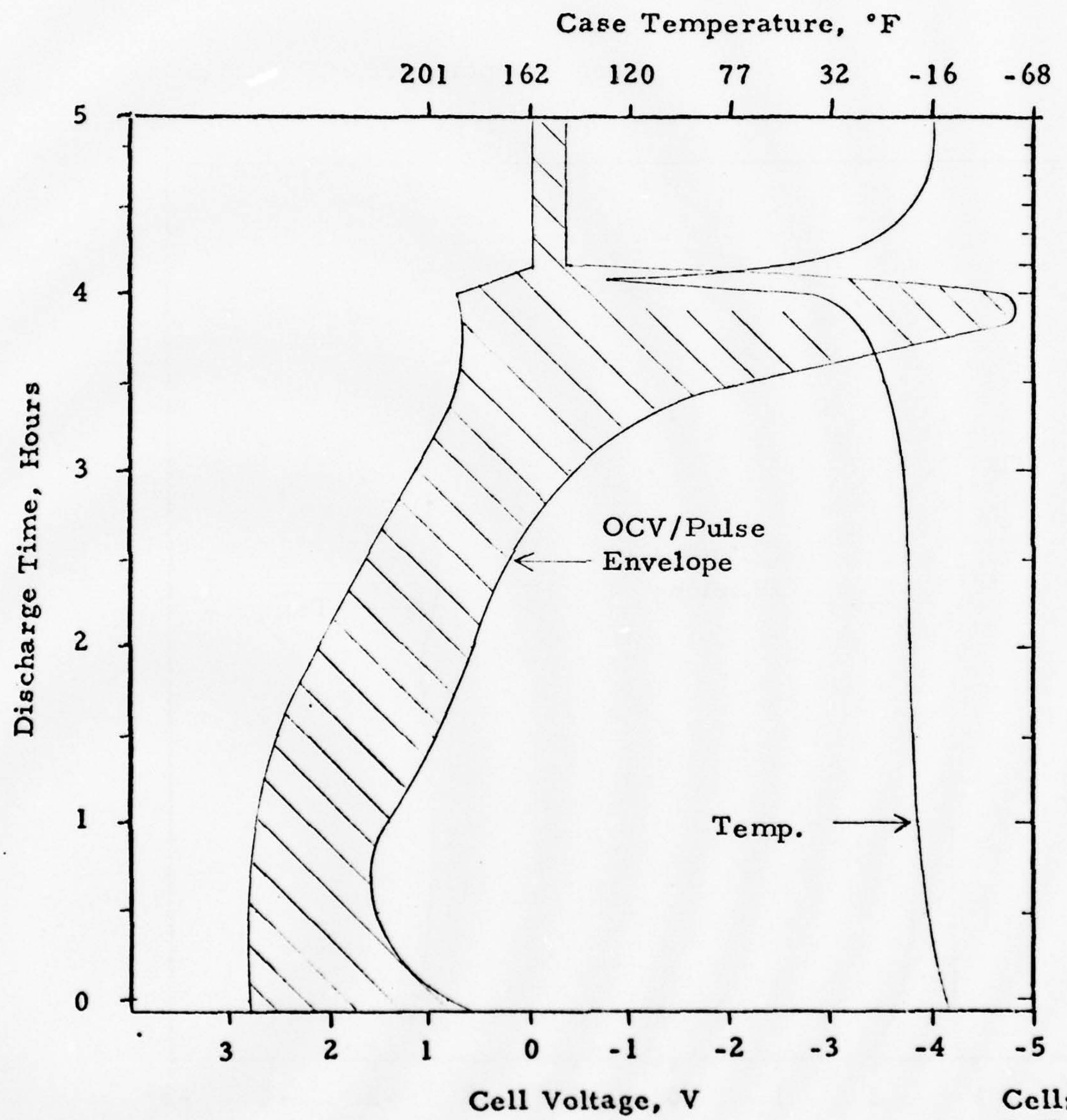


Figure 34. Performance/Safety Tests

Cell: DR304
Build: 9
Load: 20A
Temp: -20°F

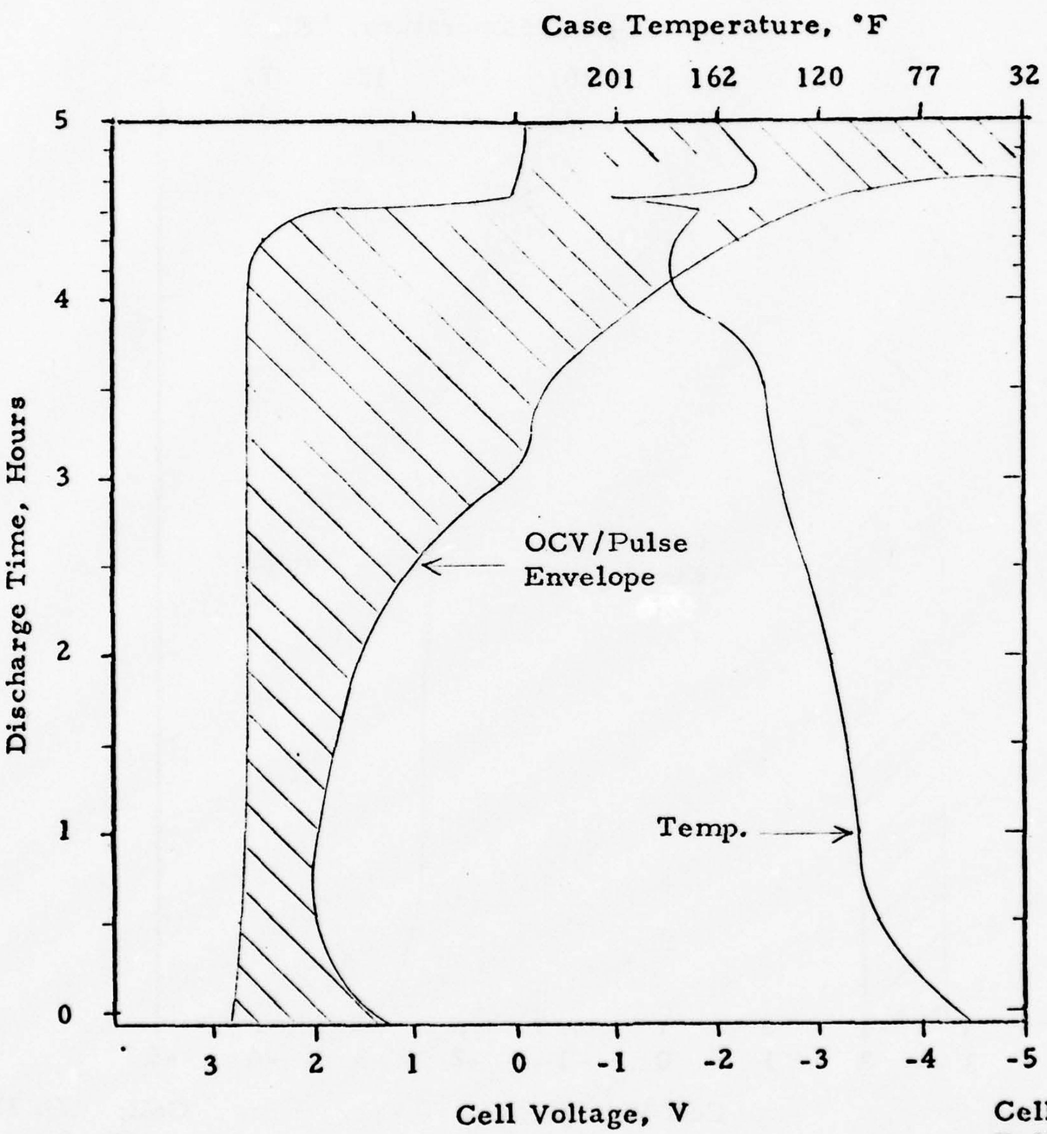


Figure 35. Performance/Safety Tests

Cell: DR339
Build: 9
Load: 20A
Temp: RT

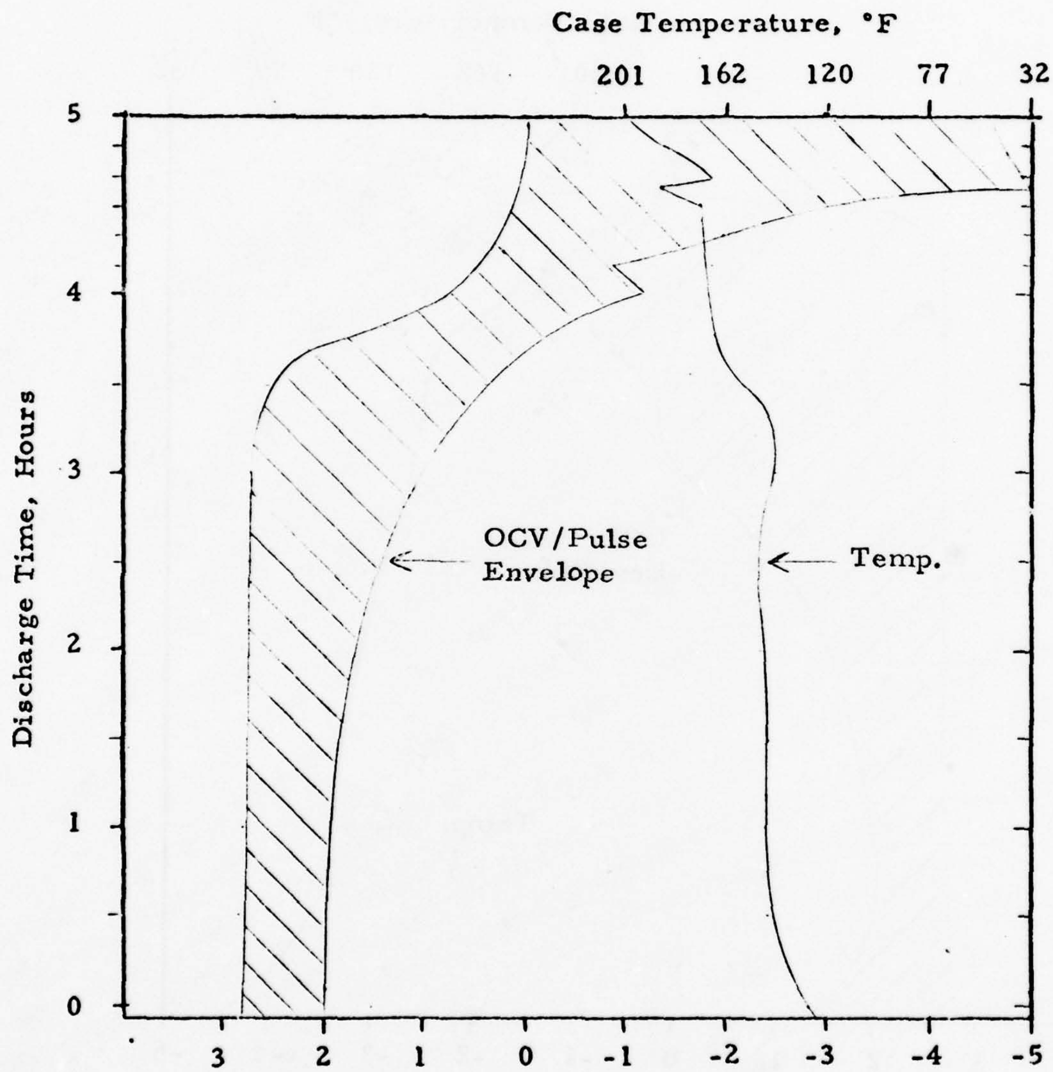


Figure 36. Performance/Safety Tests

Cell: DR338
Build: 9
Load: 20A
Temp: 130°F

Representative graphs are shown in Figures 28 to 30. The pulse data (Table XVI and Figures 18) showed a greater dependence on temperature than the constant current tests with a continuing improvement up to the 130°F discharge. With all pulsing at an average current of 2A, there was no added heating benefit from the higher current pulses. Thus, the higher current pulses caused significantly more electrode polarization, especially at the lower temperature. At a 20A pulse current at -20°F, the voltage never reached the 2.0V minimum. Representative graphs are shown in Figures 31 - 36.

Safety Results

Venting During Discharge. The cells discharged at the base current of 2A had a low incidence of venting (Table XIV) as only one (at room temperature) of the 7 cells tested did vent after being forced to a negative voltage. This is consistent with the earlier builds of essentially baseline design where sporadic or no venting was observed. The trend continued with the storage cells as none of the seven cells, discharged at 2A following 2 weeks at 160°F storage, vented.

At 3.5 and 5A and the 10 and 20A pulses, (Tables XIV and XVI), the trend was reversed as 12 of the 14 cells tested vented on forced discharged to a negative voltage. Surprisingly, the 2 cells that did not vent were at the low temperature (-20°F) where venting was more prevalent in the early program (1).

In general, the cells that were pulse discharged vented at a higher case temperature and were considered to be less safe. Loud "pops" were heard on venting and the vent area was usually opened wider which would be more indicative of a more rapid and higher pressure expulsion of gases.

The case temperature at venting was usually close to 100°F for the -20°F test and 200°F for both the room temperature and 130°F tests. Although the actual

Table XVII

SHORT CURCUIT TEST RESULTS

Cell No.	Temp. (°F)	Peak Current (A)	Time at Peak (min.)	Time To Vent (min.)	Case Temp. at Vent °F	Comment
DR261	-20	53A	1.3	2.1	64	
263		40	.9	-	-	Internal lead loss
265		46	2.0	2.9	42	
343	RT	70	0.7	1.0	129	
344		62	0.7	0.9	134	
345		50	0.1	-	-	Internal lead loss
279	130	65	0.1	0.7	150	
278		54	0.3	-	-	Internal lead loss
277		56	0.1	0.8	166	

venting was not observed for both safety and equipment limitations, the venting was considered safe as these relatively low temperatures were not indicative of violent venting or even venting with flame. Slight black discoloration was noted on some of the vented cells but it was more likely this was from expelled and decomposed electrolyte than from charring due to flame as the vented cases were no more distorted than those from standard short circuit tests.

Short Circuit Tests

Short circuiting the cells under the -20 to 130^{o}F range of temperature indicated no safety problem with the cells venting without flame between 0.7 and 2.9 minutes (Table XVII). The 40 to 70A achieved by the cells did reveal a design weakness as one cell from each group failed to vent because of a loss of internal continuity. Post mortem analysis showed the 0.003" nickel anode lead was too thin to sustain the high currents and broke apart before the cell could heat sufficiently to cause venting. Although the lead loss did not appear to create a safety problem, a return to the 0.005" thick lead but not necessarily the diagonal collector, was recommended for future use.

DISCUSSION

The last build of our initial safety study contract (1) indicated we were nearing our performance goals and safety requirements with a new high rate "D" cell design. The start of this study showed that on the average, better than 4 and 8 Ahrs. at -20^{o}F and room temperature, respectively, could be attained with a cell that did not vent through a 2A forced discharge of 200% of the theoretical SO_2 capability. This controlled build verified that, with the lithium limited design and improvements in the anode current collection and especially the cathode composition and processing technique, an efficient and safe high rate SO_2 cell could be fabricated. It was generally concluded that high cathode efficiency together with a lithium limited cell will maintain the safe nature of the cell. This generally supports the conclusions of an earlier study (3).

The most significant improvement from this study is the development of the high rate cathode. Combining a low level of Teflon with dry roll forming technique has produced a process that is readily adaptable to high rate production. Carbon and Teflon mix weight has remained as the key variable to achieving an optimum cathode. Figure 37 shows the correlation of capacity and carbon mix weight, as discussed in b. (3) (Figure 10), with data from all four builds from this study. The added data supports the correlation and again suggests maximizing the carbon mix weight for optimum performance.

The porosimetry measurements (Table VIII) concur with this direction as there appears to be no loss in surface area as the density increases. Unfortunately the limited porosimetry data gave no indication on the practical limit of density as a limiting pore size and volume must eventually be reached. Lack of repeatability of porosimetry measurements suggests non-uniformity of the cathode. Areas of varying density and pore size throughout the cathode would tend to support the capacity to carbon/Teflon weight correlation and at the same time, explain

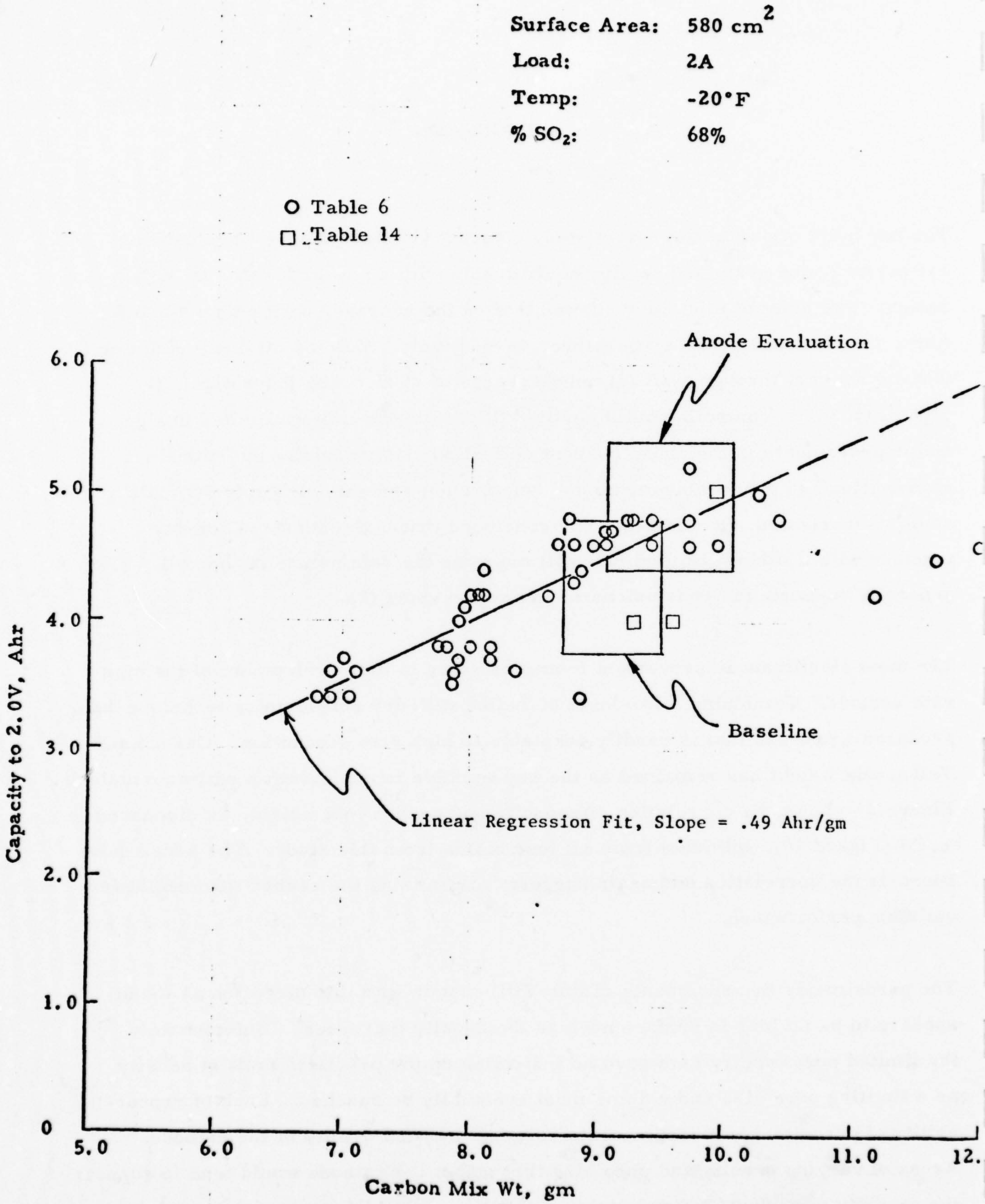


Figure 37

Capacity vs. Carbon Mix Weight

the observed data spread. More work is definitely needed to understand the cathode structure and the relation to performance and safety.

Variation of the lithium content indicated that up to a Li/SO_2 ratio of 1.2 will not decrease the safety to forced discharge at 2 amperes. The sample size of this test was small and confined to one temperature and verification is suggested before conclusions are drawn. The ±10% thickness tolerance on the thin lithium required for high rate designs may require up to a Li/SO_2 ratio of 1.2 on high production "D" cells required to deliver 8 Ahr. at room temperature.

The addition of aluminum to the lithium as a means of lowering the lithium content while maintaining continuity under deep discharge produces a hazardous cell and should not be considered. Reference to hazardous reactions on aluminum have been discussed before (4). The acceptability of any form of aluminum in Li/SO_2 cells, such as the aluminum collector grid, from a safety viewpoint, requires further study.

One possible modification to our baseline design is in the anode lead. Maintaining the nickel at a thickness of 0.003" is necessary to minimize shorting during the wrapping operation. However, the extension of this lead beyond the lithium to the case weld has been shown to cause a problem during short circuit. Overheating and eventual disintegration of this lead at high currents is not recommended for safe operation. A nickel lead of at least 0.005", welded to the anode collector will be substituted in the future.

This study verified the baseline high rate design as acceptable for performance and safety on a 2A forced discharge to 200% of the theoretical SO_2 capacity. As the current is increased to 5A, however, there is an increased probability of venting if the cells are driven into reverse. Forced pulsing at 10 and 20A beyond a reasonable cutoff voltage can lead to rapid venting; however, the lithium limited configuration still alleviates the potential for explosion when a cell is forced into reverse.

REFERENCES

(1) L. J. Blagdon, B. Randall, "Safety Studies of Lithium-Sulfur Dioxide Cells" ERADCOM Report, Contract DELET-TR-77-0459 February 1979.

(2) "Manufacturing Methods for Lithium Batteries", Honeywell Power Sources Center, Technical Report AFML-TR-79-4084, 31 August 1979.

(3) Gabriel J. DiMasi and John A. Christopolus, "The Effects of the Electrochemical Design Upon the Safety and Performance of the Lithium-Sulfur Dioxide Cells" Proc. 28th Power Sources Symposium, June 1978.

(4) H. Taylor, William Bowden and J. Barrella, "Li/SO_2 Cells of Improved Stability" Proc. 28th Power Sources Symposium, June 1978.

SECTION 5.0
ACKNOWLEDGEMENTS

The continuing guidance and encouragement provided by G. J. DiMasi and E. S. Brooks is acknowledged and appreciated.

APPENDICES

APPENDIX I

STATISTICAL ANALYSIS OF BASELINE (G3091-B7) CELL DISCHARGE TESTS

A) Assuming (1) G3091-B7 discharge performance is normally distributed, and (2) the sample statistics at Ambient and -20°F are true estimates of the population parameters, the one-sided tolerance limit can be calculated for cell performance.

$$L1 = \overline{X} - K_{(\gamma,\ 1-\alpha)}\, s$$

where: L1 is the one-sided limit

$\overline{X}$ is the sample mean

s is the sample standard deviation

$K_{(\gamma,\ 1-\alpha)}$ is a factor based on a confidence level of 0.90 and probability of 0.95 for sample size "n"

At Ambient temperature,

$n = 15$

$\overline{X} = 4.20$ hours

$s = 0.0716$ hours

$K_{(.90,\ .95)} = 2.329$

$$L = \overline{X} - Ks = 4.20 - (2.329)(0.0716) = 4.03 \text{ hours}$$

and at -20°F,

$n = 15$

$\overline{X} = 2.19$ hours

$s = 0.161$ hours

$K_{(.90,\ .95)} = 2.329$

$$L = \overline{X} - Ks = 2.19 - (2.329)(0.161) = 1.81 \text{ hours}$$

Therefore, we can state with 90% confidence that 95% of the G3091-B1 discharge times, at 2.0 Amperes Constant Current discharge to 2.0 volts, will be greater than:

4.03 hours @ Ambient temperature
and 1.81 hours @ -20°F

Since 2.0 hours is the specified minimum discharge time at -20°F, we can calculate the value for K at 2.0 hours and find an approximate value for the proportion of cells expected to be discharged greater than 2.0 hours.

$$\text{thus: } K = \frac{\overline{X} - 2.0 \text{ hours}}{s} = \frac{2.19 - 2.0}{0.161} = 1.18$$

The closest table value (at 90% confidence) to a K of 1.18 is K = 1.119 corresponding to 75%.

therefore: $L = \overline{X} - Ks = 2.19 - (1.119)(0.161) = 2.01$ hours
so, at 90% confidence, 75% of G3091-B1 discharge times to 2.0 volts at -20°F . . . will be greater than 2.01 hours

B) During forced discharge (at 2.0 Amperes) to 187% of theoretical capacity, a cell vent would be considered a failure of the G3091-B7 cell design to prevent venting.

Fifteen (15) cells were tested at each test temperature (i.e., Ambient and -20°F). No failures (r) were encountered. Estimates of Reliability can be calculated using the sample size (n) and number of failures (r) which will estimate the minimum reliability demonstrated by the tests:

$$R = \frac{1}{\left[1 + \left(\frac{r+1}{n-r} \cdot F\ (2r+2,\ 2n-2r)\right)\right]}$$

where: R is the reliability estimate (Lower Limit)
n is the sample size
r is the number of failures
$F_{\alpha}(2r+2,\ 2n-2r)$ is F - distribution value corresponding to $2r + 2$ and $2n - 2r$ degrees of Freedom for α level of significance. ($1 - \alpha$ is confidence level)

At both Ambient and -20°F temperatures:

$n = 15$
$r = 0$
$F_{\alpha}(2, 30) = 2.49$
$\alpha = 0.10$

degrees of Freedom
$2r + 2 = 2(0) + 2 = 2$
$2n - 2r = 2(15) - 2(0) = 30$

$$R = \frac{1}{\left[1 + \left(\frac{0+1}{15-0} \cdot 2.49\right)\right]} = \frac{1}{[1 + (0.166)]}$$

$$= 0.8576 \text{ or } 85.76\%$$

Therefore, the Minimum Reliability associated with no venting under conditions of 2.0 Amperes forced discharge to 187% of theoretical capacity is 85.76% at 90% confidence at Ambient and -20°F temperatures.

APPENDIX 2

POROSIMETRY DATA

**************MICROMERITICS**************

MATERIALS ANALYSIS LABORATORY

MODEL 900 AND 910
POROSIMETER DATA AND CALCULATIONS

OPERATOR(S): MLB DATE RUN: 092878

SAMPLE IDENTIFICATION: HONEYWELL GROUP 2

CELL FACTOR: .000788 WEIGHTS, WC: 42.5968 GRAMS
VC: 24.056 CC WS: .3718 GRAMS
CT: 119 WT: 356.64 GRAMS

A APPLIED PRESSURE	C CORRECTED COUNTER INDICATION B-BLANK RES	D PORE DIAMETER (2X EQ 2)	E VOL OF PORES OF INDICATED DIA. AND > (C*FACTOR/WS)	F PERCENT OF TOTAL POROSITY
1	0	176.76	0	0
2	4	88.38	.00847767	.711744
4	12	44.19	.025433	2.13523
6	19	29.46	.040269	3.38078
8	25	22.095	.0529855	4.4484
10	33	17.676	.0699408	5.87189
12	41	14.73	.0868962	7.29537
14.2	54	12.4479	.114449	9.60854
20	56	8.838	.118687	9.96441
40	57	4.419	.120807	10.1423
60	71	2.946	.150479	12.6334
80	86	2.2095	.18227	15.3025
100	180	1.7676	.381495	32.0285
200	232	.8838	.491705	41.2811
400	284	.4419	.601915	50.5338
600	313	.2946	.663378	55.6939
800	333	.22095	.705766	59.2527
1000	360	.17676	.762991	64.0569
2000	475	.08838	1.00672	84.5196
4000	542	.04419	1.14872	96.4413
6000	551	.02946	1.1678	98.0427
8000	556	.022095	1.1784	98.9324
10000	561	.017676	1.18899	99.8221
15000	561	.011784	1.18899	99.8221
20000	562	.008838	1.19111	100
25000	562	.0070704	1.19111	100
30000	562	.005892	1.19111	100
35000	562	.00505028	1.19111	100
40000	562	.004419	1.19111	100
45000	562	.003928	1.19111	100
50000	562	.0035352	1.19111	100

NET PORE VOLUME 1.19111 CC/G

******************MICROMERITICS******************

MATERIALS ANALYSIS LABORATORY

MODEL 900 AND 910
POROSIMETER DATA AND CALCULATIONS

OPERATOR(S): MLB DATE RUN: 092978

SAMPLE IDENTIFICATION: HONEYWELL GROUP 4

CF FACTOR: .000788 WEIGHTS, WC: 42.5919 GRAMS
VC: 24.056 CC WS: .5359 GRAMS
CT: 91 WT: 353.73 GRAMS

A APPLIED PRESSURE	C CORRECTED COUNTER INDICATION B-BLANK RES	D PORE DIAMETER (2X EQ 2)	E VOL OF PORES OF INDICATED DIA. AND > (C*FACTOR/WS)	F PERCENT OF TOTAL POROSITY
1.5	14	117.84	.0205859	1.55729
2	42	88.38	.0617578	4.67185
4	66	44.19	.097048	7.34149
6	79	29.46	.116163	8.78754
8	90	22.095	.132338	10.0111
10	100	17.676	.147042	11.1235
12	108	14.73	.158806	12.0133
14.2	122	12.4479	.179392	13.5706
20	184	8.838	.270558	20.4672
40	242	4.419	.355842	26.9188
60	272	2.946	.399955	30.2558
80	290	2.2095	.426423	32.2581
100	313	1.7676	.460243	34.8165
200	383	.8838	.563172	42.6029
[illegible]	463	.4419	.680806	51.5017
[illegible]	510	.2946	.749916	56.7297
[illegible]00	539	.22095	.792558	59.9555
1000	573	.17676	.842553	63.7375
2000	774	.08838	1.13811	86.0957
4000	871	.04419	1.28074	96.8854
6000	888	.02946	1.30574	98.7764
8000	894	.022095	1.31456	99.4438
10000	898	.017676	1.32044	99.8887
15000	898	.011784	1.32044	99.8887
21000	899	.00841714	1.32191	100
25000	899	.0070704	1.32191	100
30000	899	.005892	1.32191	100
[illegible]5000	899	.00505028	1.32191	100
40000	899	.004419	1.32191	100
45000	899	.003928	1.32191	100
50000	899	.0035352	1.32191	100

NET PORE VOLUME 1.32191 CC/G

********************MICROMERITICS********************

MATERIALS ANALYSIS LABORATORY

MODEL 900 AND 910
POROSIMETER DATA AND CALCULATIONS

OPERATOR(S): MLB   DATE RUN: 100278

SAMPLE IDENTIFICATION: HONEYWELL GROUP 5

[illegible] 000787	WEIGHTS,	WC:	42.5911 GRAMS
[illegible] .086 CC		WS:	.8244 GRAMS
[illegible] 147		WT:	351.03 GRAMS

A APPLIED PRESSURE	C CORRECTED COUNTER INDICATION B-BLANK RES	D PORE DIAMETER (2X EQ 2)	E VOL OF PORES OF INDICATED DIA. AND > (C*FACTOR/WS)	F PERCENT OF TOTAL POROSITY
1	0	176.76	0	0
2	7	88.38	.00668243	.645161
[illegible]	20	44.19	.0190927	1.84332
[illegible]	30	29.46	.028639	2.76498
8	42	22.095	.0400946	3.87097
10	54	17.676	.0515502	4.97696
12	60	14.73	.057278	5.52995
14.2	81	12.4479	.0773253	7.46544
20	158	8.838	.150832	14.5622
40	213	4.419	.203337	19.6313
60	232	2.946	.221475	21.3825
80	265	2.2095	.252978	24.424
100	278	1.7676	.265388	25.6221
200	359	.8838	.342713	33.0875
[illegible]	456	.4419	.435313	42.0276
[illegible]	517	.2946	.493546	47.6498
800	557	.22095	.531731	51.3364
1000	615	.17676	.5871	56.682
2000	782	.08838	.746523	72.0737
4000	1050	.04419	1.00237	96.7742
6000	1070	.02946	1.02146	98.6175
[illegible]	1076	.022095	1.02719	99.1705
[illegible]	1080	.017676	1.031	99.5392
[illegible]	1080	.011784	1.031	99.5392
20000	1085	.008838	1.03578	100
25000	1085	.0070704	1.03578	100
30000	1085	.005892	1.03578	100
[illegible]	1085	.00505028	1.03578	100
40000	1085	.004419	1.03578	100
45000	1085	.003928	1.03578	100
50000	1085	.0035352	1.03578	100

NET PORE VOLUME 1.03578 CC/G

************MICROMERITICS**************

MATERIALS ANALYSIS LABORATORY

MODEL 900 AND 910
POROSIMETER DATA AND CALCULATIONS

OPERATOR(S): MLB   DATE RUN: 092278

SAMPLE IDENTIFICATION: HONEYWELL GROUP 6

CELL FACTOR: .000788   WEIGHTS,   WC: 42.623 GRAMS
VC: 24.056 CC   WS: .459 GRAMS
CT: 124   WT: 353.18 GRAMS

A APPLIED PRESSURE	C CORRECTED COUNTER INDICATION B-BLANK RES	D PORE DIAMETER (2X EQ 2)	E VOL OF PORES OF INDICATED DIA. AND > (C*FACTOR/WS)	F PERCENT OF TOTAL POROSITY
1	0	176.76	0	0
2	6	88.38	.0103006	.646552
4	17	44.19	.0291852	1.8319
6	25	29.46	.0429194	2.69397
8	36	22.095	.0618039	3.87931
10	47	17.676	.0806884	5.06465
12	61	14.73	.104723	6.57328
14.2	63	12.4479	.108157	6.78879
20	76	8.838	.130475	8.18966
40	78	4.419	.133908	8.40517
200	346	.8838	.594004	37.2845
440	454	.401727	.779416	48.9224
600	491	.2946	.842937	52.9095
800	525	.22095	.901307	56.5733
1000	546	.17676	.937359	58.8362
2000	739	.08838	1.2687	79.6336
4000	895	.04419	1.53651	96.444
6000	913	.02946	1.56742	98.3836
8000	923	.022095	1.58458	99.4612
10000	923	.017676	1.58458	99.4612
15000	924	.011784	1.5863	99.569
20000	928	.008838	1.59317	100
25000	928	.0070704	1.59317	100
30000	928	.005892	1.59317	100
35000	928	.00505028	1.59317	100
40000	928	.004419	1.59317	100
45000	928	.003928	1.59317	100
50000	928	.0035352	1.59317	100

NET PORE VOLUME 1.59317 CC/G

**************MICROMERITICS**************

MATERIALS ANALYSIS LABORATORY

MODEL 900 AND 910
POROSIMETER DATA AND CALCULATIONS

OPERATOR(S): MLB DATE RUN: 081878

SAMPLE IDENTIFICATION: HONEYWELL GROUP 8

CELL FACTOR: .000787
VC: 24.086 CC
CT: 45

WEIGHTS, WC: 42.4831 GRAMS
WS: .4355 GRAMS
WT: 357.72 GRAMS

A APPLIED PRESSURE	C CORRECTED COUNTER INDICATION B-BLANK RES	D PORE DIAMETER (2X EQ 2)	E VOL OF PORES OF INDICATED DIA. AND > (C*FACTOR/WS)	F PERCENT OF TOTAL POROSITY
1	0	176.76	0	0
2	3	88.38	.00542135	.653595
4	9	44.19	.0162641	1.96078
6	16	29.46	.0289139	3.48584
8	23	22.095	.0415637	5.01089
10	29	17.676	.0524064	6.31808
12	37	14.73	.0668634	8.061
14.2	52	12.4479	.0939701	11.329
30	88	5.892	.159026	19.1721
40	91	4.419	.164448	19.8257
65	134	2.71938	.242154	29.1939
80	140	2.2095	.252997	30.5011
130	173	1.35969	.312631	37.6906
220	205	.803454	.370459	44.6623
400	241	.4419	.435515	52.5054
700	272	.252514	.491536	59.2593
800	274	.22095	.49515	59.695
1000	281	.17676	.5078	61.22
2000	380	.08838	.686705	82.7887
4000	431	.04419	.778868	93.8998
6000	440	.02946	.795132	95.8605
8000	443	.022095	.800553	96.5141
10000	446	.017676	.805974	97.1677
15000	446	.011784	.805974	97.1677
20000	455	.008838	.822239	99.1285
25000	455	.0070704	.822239	99.1285
31000	459	.00570193	.829467	100
35000	459	.00505028	.829467	100
40000	459	.004419	.829467	100
45000	459	.003928	.829467	100
50000	459	.0035352	.829467	100

NET PORE VOLUME .829467 CC/G
SKELETAL DENSITY AT HIGHEST PRESSURE-11.1896 G/CC
BULK DENSITY .550384 G/CC

**************MICROMERITICS**************

MATERIALS ANALYSIS LABORATORY

MODEL 900 AND 910
POROSIMETER DATA AND CALCULATIONS

OPERATOR(S): MLB   DATE RUN: 091878

SAMPLE IDENTIFICATION: HONEYWELL GROUP 10

CELL FACTOR: .000787   WEIGHTS, WC: 42.5269 GRAMS
VC: 24.086 CC   WS: .57 GRAMS
CT: 63   WT: 352.47 GRAMS

A APPLIED PRESSURE	C CORRECTED COUNTER INDICATION B-BLANK RES	D PORE DIAMETER (2X EQ 2)	E VOL OF PORES OF INDICATED DIA. AND > (C*FACTOR/WS)	F PERCENT OF TOTAL POROSITY
1	2	176.76	.0027614	.183823
2	10	88.38	.013807	.919117
4	29	44.19	.0400403	2.66544
6	43	29.46	.0593702	3.9522
8	57	22.095	.0787	5.23897
10	72	17.676	.0994105	6.61765
12	93	14.73	.128405	8.54779
14.2	116	12.4479	.160161	10.6618
25	203	7.0704	.280282	18.6581
60	304	2.946	.419733	27.9412
90	360	1.964	.497052	33.0882
220	506	.803454	.698635	46.5073
400	587	.4419	.810472	53.9522
600	641	.2946	.88503	58.9154
800	677	.22095	.934735	62.2242
1200	732	.1473	1.01067	67.2794
2000	910	.08838	1.25644	83.6397
4000	1055	.04419	1.45664	96.9669
6000	1070	.02946	1.47735	98.3456
8000	1074	.022095	1.48287	98.7132
10000	1077	.017676	1.48702	98.9889
15000	1077	.011784	1.48702	98.9889
20000	1082	.008838	1.49392	99.4485
25000	1082	.0070704	1.49392	99.4485
30000	1088	.005892	1.5022	100
35000	1088	.00505028	1.5022	100
40000	1088	.004419	1.5022	100
45000	1088	.003928	1.5022	100
50000	1088	.0035352	1.5022	100

NET PORE VOLUME 1.5022 CC/G

**************MICROMERITICS**************

MATERIALS ANALYSIS LABORATORY

MODEL 900 AND 910
POROSIMETER DATA AND CALCULATIONS

OPERATOR(S): MLB DATE RUN: 091878

SAMPLE IDENTIFICATION: HONEYWELL GROUP 11

CELL FACTOR: .000778 WEIGHTS, WC: 55.1315 GRAMS
VC: 27.815 CC WS: .5273 GRAMS
CT: 50 WT: 414.51 GRAMS

A APPLIED PRESSURE	C CORRECTED COUNTER INDICATION B-BLANK RES	D PORE DIAMETER (2X EQ 2)	E VOL OF PORES OF INDICATED DIA. AND > (C*FACTOR/WS)	F PERCENT OF TOTAL POROSITY
1	75	176.76	.110658	6.06306
2	125	88.38	.18443	10.1051
4	180	44.19	.265579	14.5513
6	201	29.46	.296564	16.249
8	220	22.095	.324597	17.785
10	237	17.676	.349679	19.1593
12	256	14.73	.377713	20.6952
14.2	277	12.4479	.408697	22.3929
40	288	4.419	.424927	23.2821
160	565	1.10475	.833624	45.675
200	597	.8838	.880838	48.2619
500	717	.35352	1.05789	57.9628
600	743	.2946	1.09625	60.0647
800	788	.22095	1.16265	63.7025
1000	819	.17676	1.20839	66.2086
2000	1059	.08838	1.56249	85.6103
4000	1179	.04419	1.73954	95.3112
8000	1208	.022095	1.78233	97.6556
11000	1213	.0160691	1.78971	98.0598
15000	1221	.011784	1.80151	98.7065
20000	1228	.008838	1.81184	99.2724
25000	1228	.0070704	1.81184	99.2724
32000	1231	.00552375	1.81627	99.5149
35000	1231	.00505028	1.81627	99.5149
41000	1237	.00431122	1.82512	100
45000	1237	.003928	1.82512	100
50000	1237	.0035352	1.82512	100

NET PORE VOLUME 1.82512 CC/G

**************MICROMERITICS**************

MATERIALS ANALYSIS LABORATORY

MODEL 900 AND 910
POROSIMETER DATA AND CALCULATIONS

OPERATOR(S): MLB DATE RUN: 091878

SAMPLE IDENTIFICATION: HONEYWELL GROUP 12

CELL FACTOR: .000788 WEIGHTS, WC: 42.6214 GRAMS
VC: 24.056 CC WS: .3056 GRAMS
CT: 212 WT: 357.25 GRAMS

A APPLIED PRESSURE	C CORRECTED COUNTER INDICATION B-BLANK RES	D PORE DIAMETER (2X EQ 2)	E VOL OF PORES OF INDICATED DIA. AND > (C*FACTOR/WS)	F PERCENT OF TOTAL POROSITY
1	0	176.76	0	0
2	3	88.38	.0077356	.521739
4	11	44.19	.0283639	1.91304
6	17	29.46	.0438351	2.95652
8	25	22.095	.0644633	4.34783
10	33	17.676	.0850916	5.73913
12	42	14.73	.108298	7.30434
14.2	54	12.4479	.139241	9.3913
30	94	5.892	.242382	16.3478
40	97	4.419	.250118	16.8696
65	144	2.71938	.371309	25.0435
80	152	2.2095	.391937	26.4348
130	189	1.35969	.487343	32.8696
220	228	.803454	.587906	39.6522
400	278	.4419	.716832	48.3478
700	320	.252514	.825131	55.6522
800	326	.22095	.840602	56.6956
1000	332	.17676	.856073	57.7391
2000	473	.08838	1.21965	82.2609
4000	545	.04419	1.4053	94.7826
6000	558	.02946	1.43882	97.0434
8000	563	.022095	1.45171	97.913
10000	566	.017676	1.45945	98.4347
15000	566	.011784	1.45945	98.4347
20000	575	.008838	1.48266	100
25000	575	.0070704	1.48266	100
31000	575	.00570193	1.48266	100
35000	575	.00505028	1.48266	100
40000	575	.004419	1.48266	100
45000	575	.003928	1.48266	100
50000	575	.0035352	1.48266	100

NET PORE VOLUME 1.48266 CC/G
SKELETAL DENSITY AT HIGHEST PRESSURE-.373407 G/CC
BULK DENSITY .46007 G/CC

****************MICROMERITICS****************

MATERIALS ANALYSIS LABORATORY

MODEL 900 AND 910
POROSIMETER DATA AND CALCULATIONS

OPERATOR(S): MLB DATE RUN: 100578

SAMPLE IDENTIFICATION: HONEYWELL GROUP 13

CELL FACTOR: .000787 WEIGHTS, WC: 42.5007 GRAMS
VC: 24.086 CC WS: .5697 GRAMS
CT: 100 WT: 350.75 GRAMS

A APPLIED PRESSURE	C CORRECTED COUNTER INDICATION B-BLANK RES	D PORE DIAMETER (2X EQ 2)	E VOL OF PORES OF INDICATED DIA. AND > (C*FACTOR/WS)	F PERCENT OF TOTAL POROSITY
1	3	176.76	.00414428	.266193
2	8	88.38	.0110514	.709849
4	27	44.19	.0372986	2.39574
6	43	29.46	.0594014	3.81544
8	60	22.095	.0828857	5.32387
10	82	17.676	.113277	7.27595
12	101	14.73	.139524	8.96185
14.2	134	12.4479	.185111	11.89
20	134	8.838	.185111	11.89
40	136	4.419	.187874	12.0674
60	150	2.946	.207214	13.3097
80	179	2.2095	.247276	15.8829
100	445	1.7676	.614736	39.4854
200	506	.8838	.699003	44.898
500	637	.35352	.87997	56.5217
800	696	.22095	.961474	61.7569
1000	726	.17676	1.00292	64.4188
2000	947	.08838	1.30821	84.0284
4000	1102	.04419	1.52233	97.7817
6000	1113	.02946	1.53753	98.7578
8000	1124	.022095	1.55273	99.7338
10000	1127	.017676	1.55687	100
16000	1127	.0110475	1.55687	100
20000	1127	.008838	1.55687	100
25000	1127	.0070704	1.55687	100
30000	1127	.005892	1.55687	100
35000	1127	.00505028	1.55687	100
40000	1127	.004419	1.55687	100
45000	1127	.003928	1.55687	100
50000	1127	.0035352	1.55687	100

NET PORE VOLUME 1.55687 CC/G

**************MICROMERITICS**************

MATERIALS ANALYSIS LABORATORY

MODEL 900 AND 910
POROSIMETER DATA AND CALCULATIONS

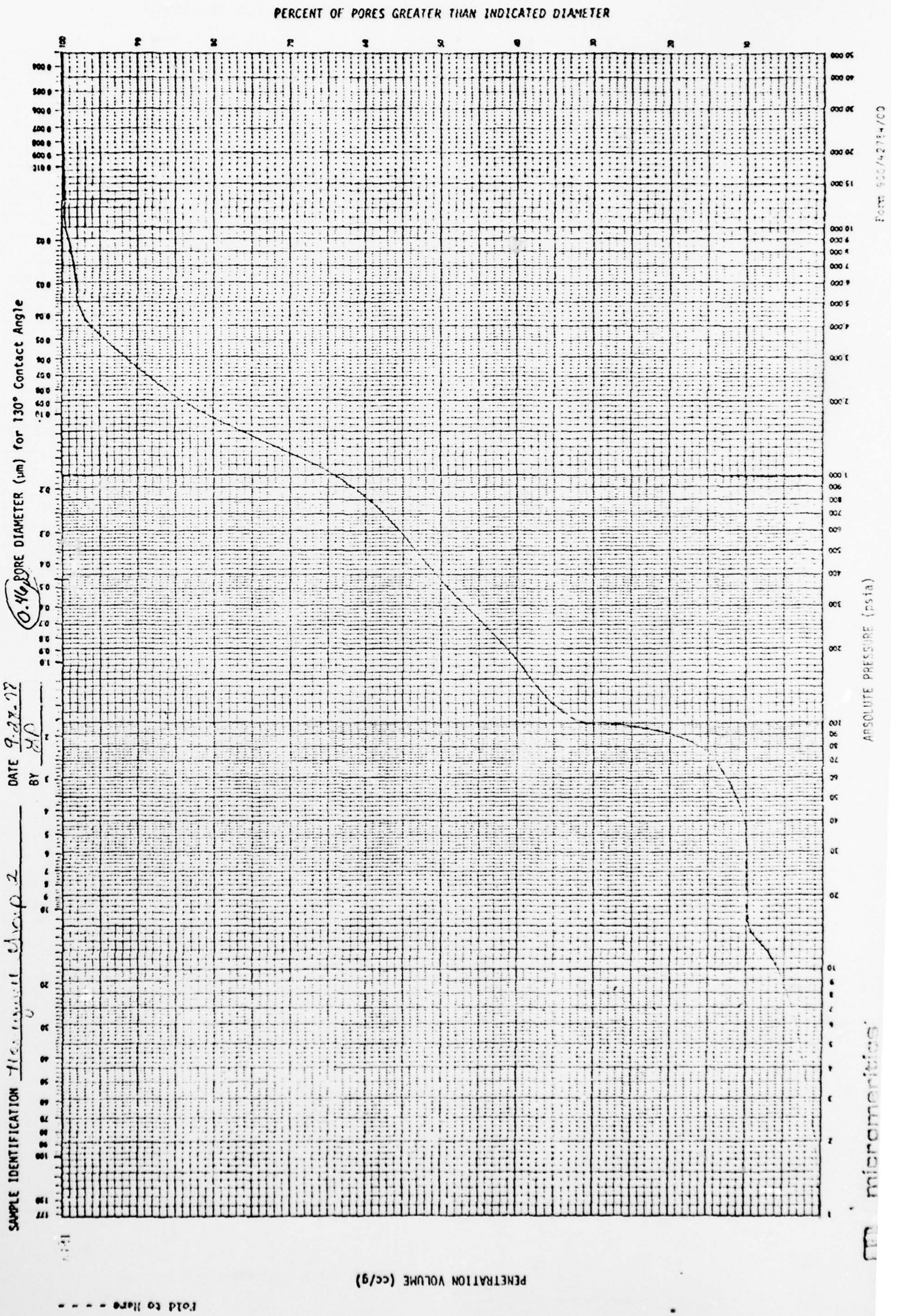
OPERATOR(S): MLB DATE RUN: 100278

SAMPLE IDENTIFICATION: HONEYWELL GROUP 14

CELL FACTOR: .000788 WEIGHTS, WC: 42.4767 GRAMS
VC: 24.056 CC WS: .7649 GRAMS
CT: 176 WT: 345.01 GRAMS

A	C	D	E	F
	CORRECTED		VOL OF PORES	
	COUNTER	PORE	OF INDICATED	PERCENT
APPLIED	INDICATION	DIAMETER	DIA. AND >	OF TOTAL
PRESSURE	B-BLANK RES	(2X EQ 2)	(C*FACTOR/WS)	POROSITY
1	0	176.76	0	0
2	8	88.38	.0082416	.629426
4	29	44.19	.0298758	2.28167
6	45	29.46	.046359	3.54052
8	63	22.095	.0649026	4.95673
10	87	17.676	.0896274	6.845
12	103	14.73	.106111	8.10386
14.2	135	12.4479	.139077	10.6216
20	161	8.838	.165862	12.6672
40	247	4.419	.254459	19.4335
60	271	2.946	.279184	21.3218
80	318	2.2095	.327603	25.0197
100	334	1.7676	.344087	26.2785
200	451	.8838	.46462	35.4839
400	583	.4419	.600606	45.8694
600	657	.2946	.676841	51.6916
800	707	.22095	.728351	55.6255
1000	759	.17676	.781922	59.7168
2000	1041	.08838	1.07244	81.904
4000	1213	.04419	1.24963	95.4367
6000	1238	.02946	1.27539	97.4036
8000	1249	.022095	1.28672	98.2691
10000	1253	.017676	1.29084	98.5838
15000	1253	.011784	1.29084	98.5838
20000	1257	.008838	1.29496	98.8985
25000	1257	.0070704	1.29496	98.8985
30000	1258	.005892	1.29599	98.9772
35000	1258	.00505028	1.29599	98.9772
40000	1258	.004419	1.29599	98.9772
45000	1271	.003928	1.30938	100
50000	1271	.0035352	1.30938	100

NET PORE VOLUME 1.30938 CC/G


PERCENT OF PORES GREATER THAN INDICATED DIAMETER
SAMPLE IDENTIFICATION
DATE 9-27-77
BY
0.46
PORE DIAMETER (µm) for 130° Contact Angle
ABSOLUTE PRESSURE (psia)
PENETRATION VOLUME (cc/g)
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micromeritics

AD-A078 961 HONEYWELL POWER SOURCES CENTER HORSHAM PA F/G 9/1
SAFETY STUDIES OF LITHIUM-SULFUR DIOXIDE CELLS.(U)
NOV 79 L J BLAGDON , B RANDALL DAAB07-78-C-0530
UNCLASSIFIED DELET-TR-78-0530-F NL

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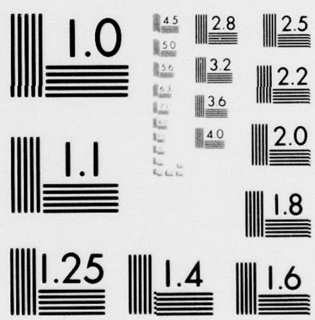
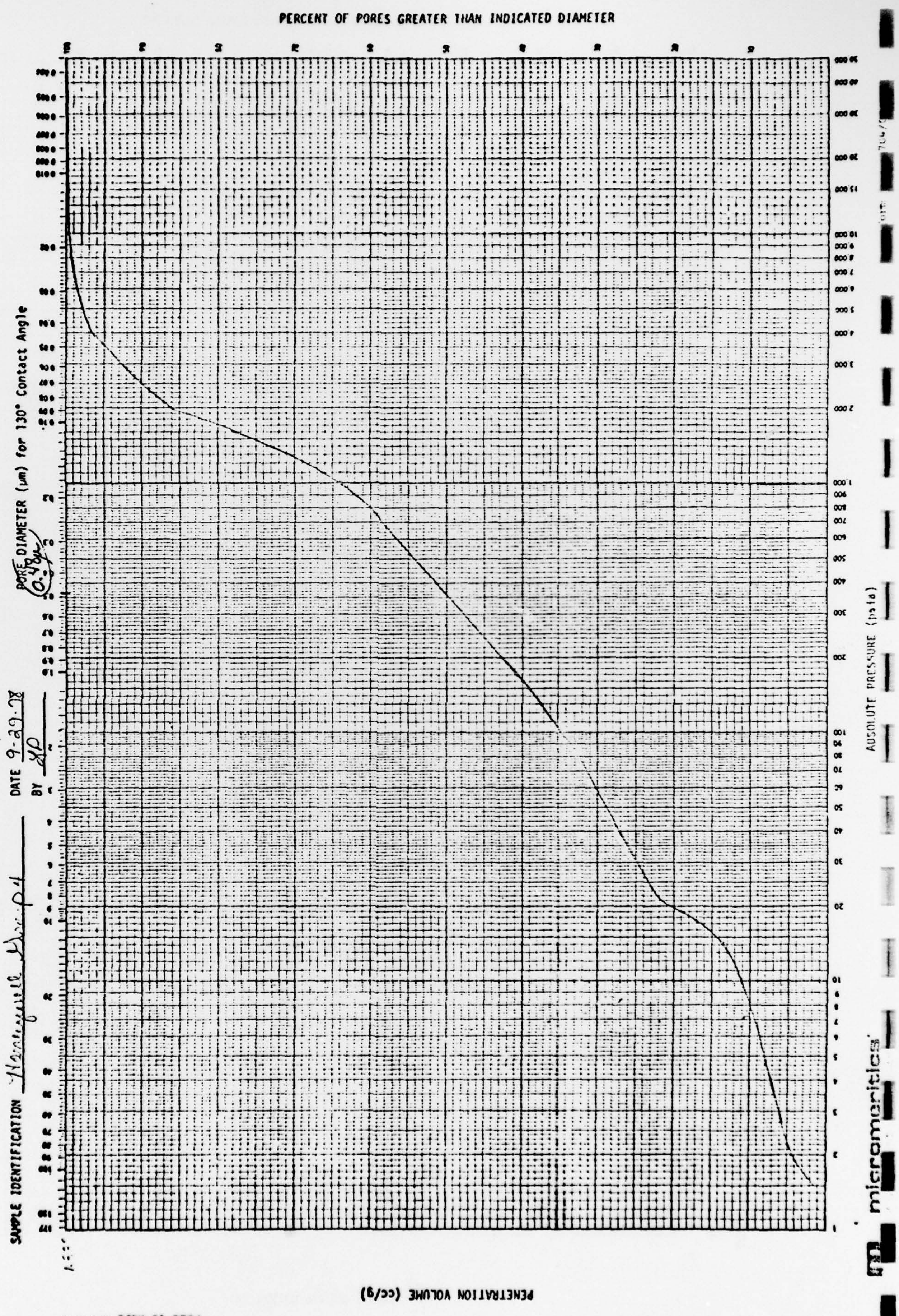
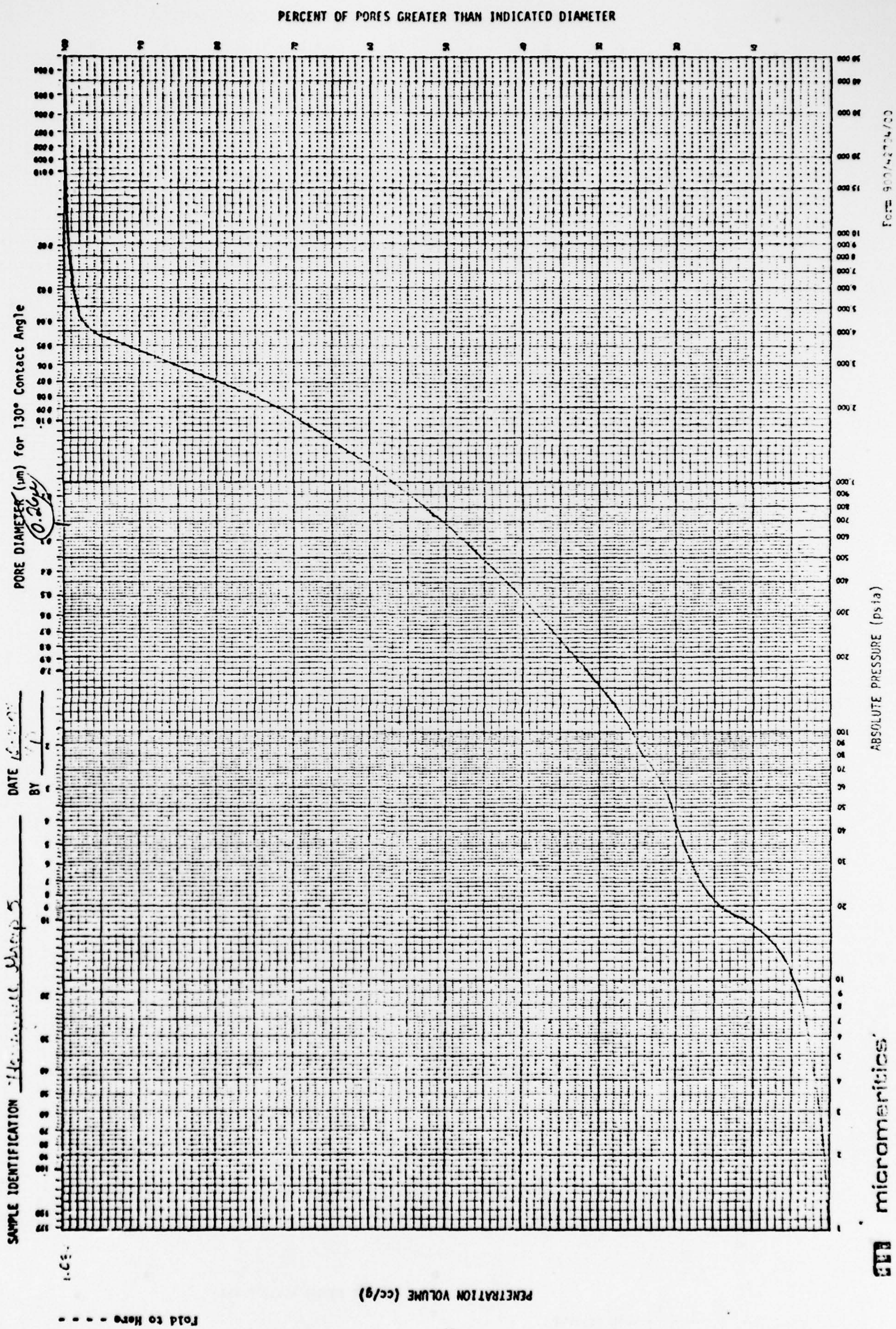
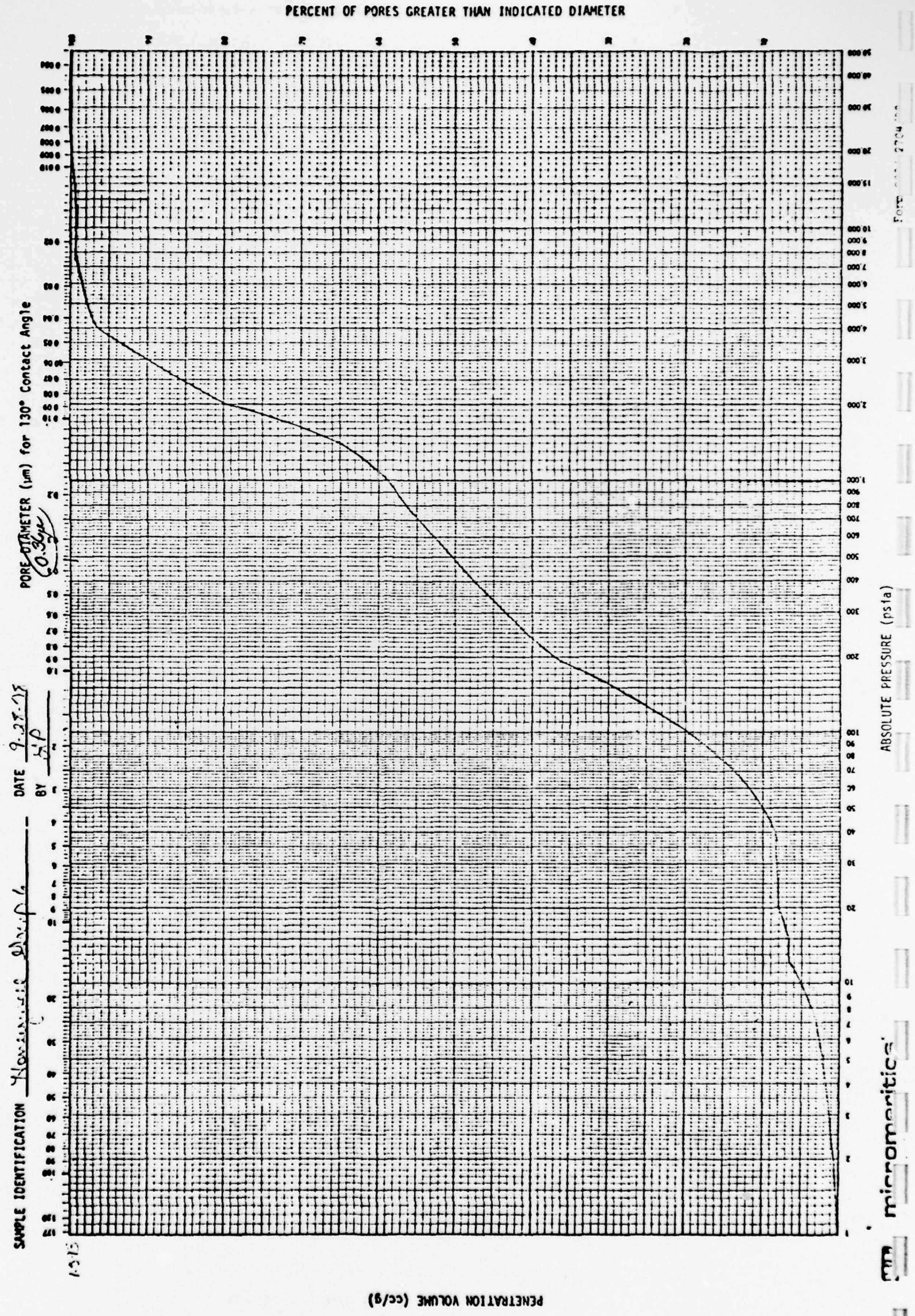


MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A


PERCENT OF PORES GREATER THAN INDICATED DIAMETER
SAMPLE IDENTIFICATION
DATE 9-29-78
BY
PORE DIAMETER (μm) for 130° Contact Angle
ABSOLUTE PRESSURE (psia)
PENETRATION VOLUME (cc/g)
Fold to Here
micromeritics


PERCENT OF PORES GREATER THAN INDICATED DIAMETER
PORE DIAMETER (μm) for 130° Contact Angle
ABSOLUTE PRESSURE (psia)
PENETRATION VOLUME (cc/g)
SAMPLE IDENTIFICATION
DATE
BY
micromeritics
Fold to Here


PERCENT OF PORES GREATER THAN INDICATED DIAMETER
PORE DIAMETER (µm) for 130° Contact Angle
(0.3µ)
SAMPLE IDENTIFICATION
DATE 9-25-75
BY
ABSOLUTE PRESSURE (psia)
PENETRATION VOLUME (cc/g)
micromeritics

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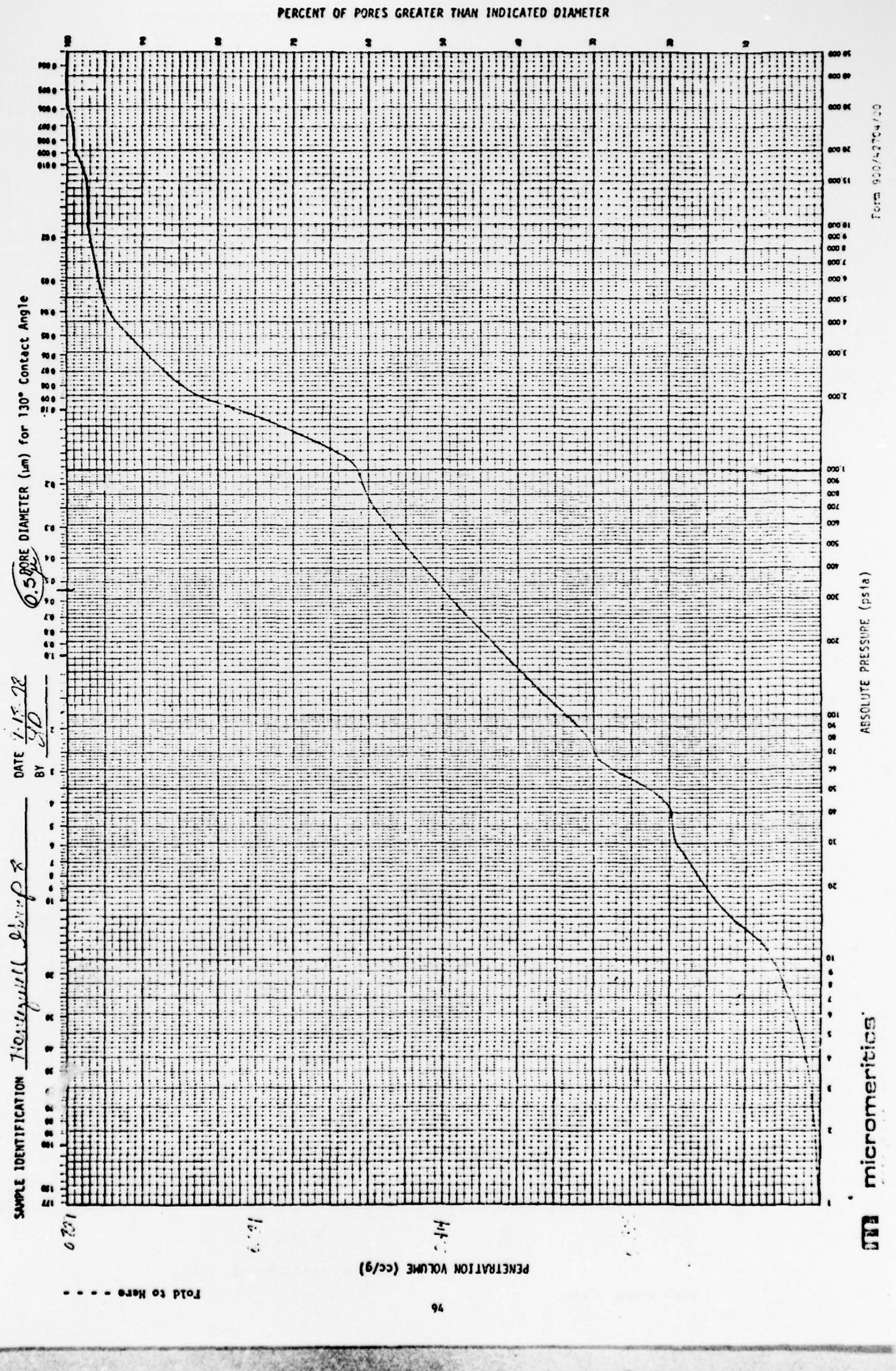
PERCENT OF PORES GREATER THAN INDICATED DIAMETER
SAMPLE IDENTIFICATION Honeywell Group X
DATE 9-15-78
BY JD
0.5μ PORE DIAMETER (μm) for 130° Contact Angle
ABSOLUTE PRESSURE (psia)
PENETRATION VOLUME (cc/g)
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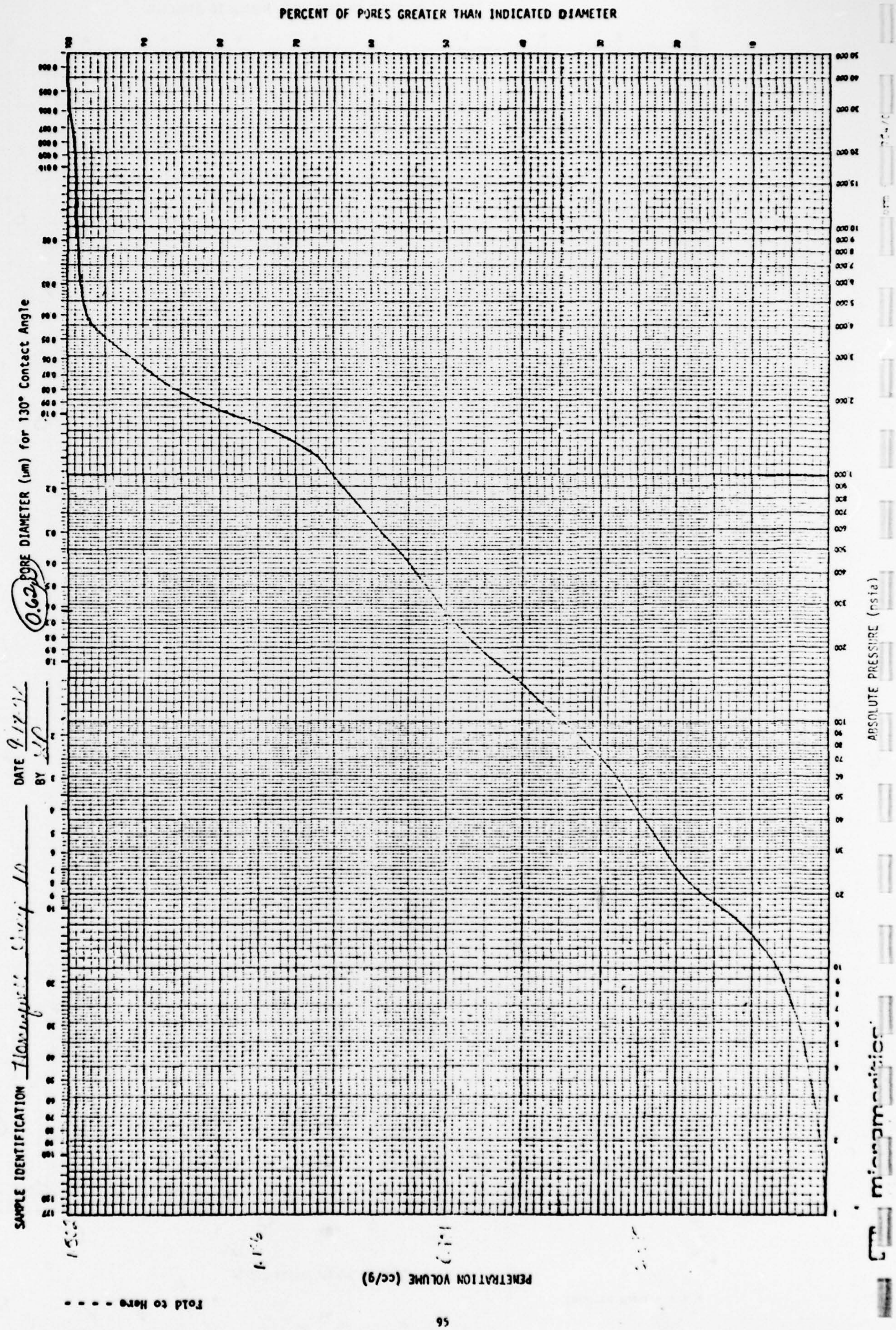
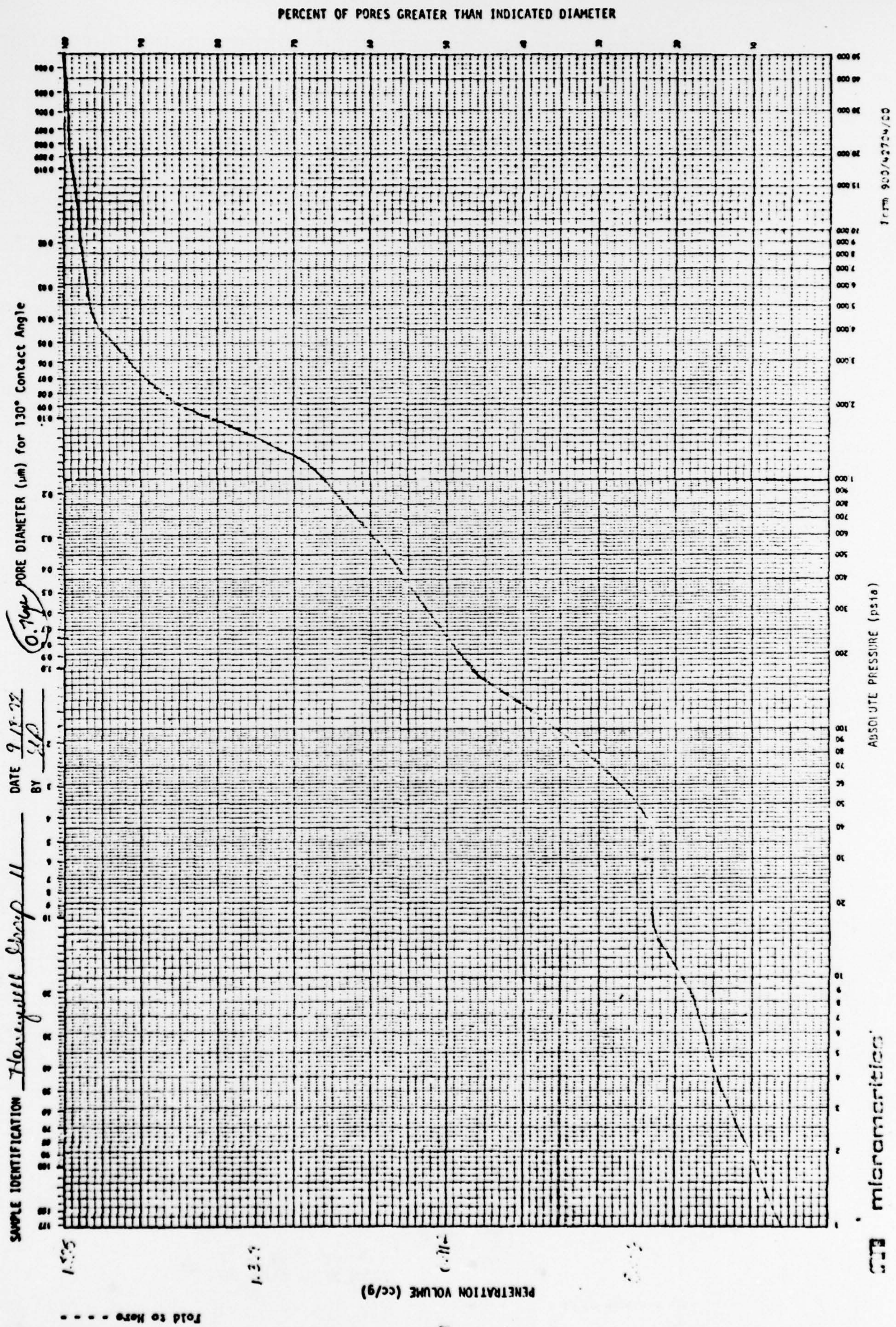
micromeritics
Form 930/42704/00


PERCENT OF PORES GREATER THAN INDICATED DIAMETER
SAMPLE IDENTIFICATION
DATE
BY
0.62μ
PORE DIAMETER (μm) for 130° Contact Angle
ABSOLUTE PRESSURE (psia)
PENETRATION VOLUME (cc/g)
Fold to Here
micromeritics



PERCENT OF PORES GREATER THAN INDICATED DIAMETER
SAMPLE IDENTIFICATION Honeywell Group 11
DATE 9-18-72
BY
0.7 Hg PORE DIAMETER (μm) for 130° Contact Angle
ABSOLUTE PRESSURE (psia)
PENETRATION VOLUME (cc/g)
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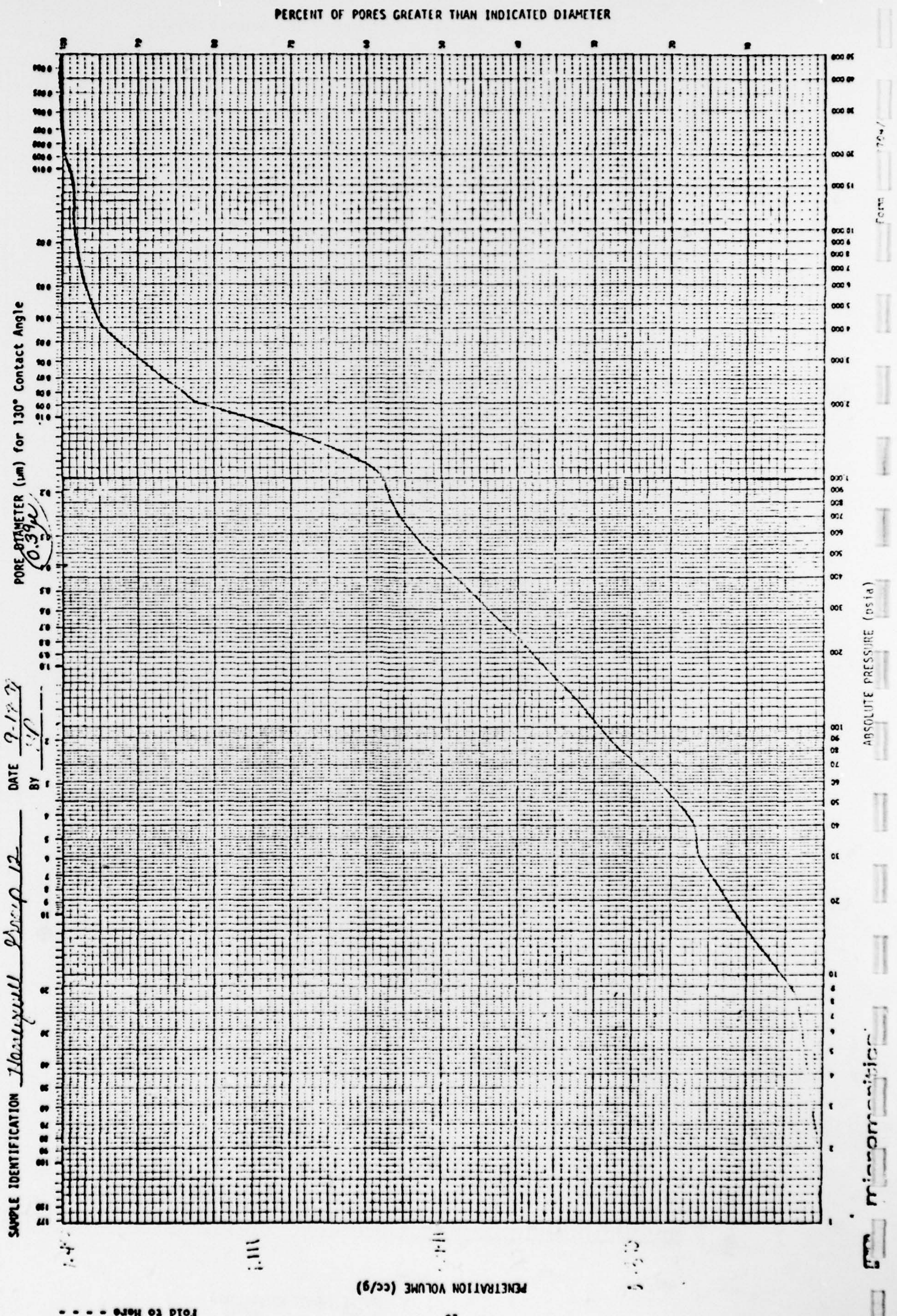
micromeritics


PERCENT OF PORES GREATER THAN INDICATED DIAMETER
PORE DIAMETER (μm) for 130° Contact Angle
(0.39μ)
ABSOLUTE PRESSURE (psia)
SAMPLE IDENTIFICATION Honeywell Group 12
DATE
BY
PENETRATION VOLUME (cc/g)
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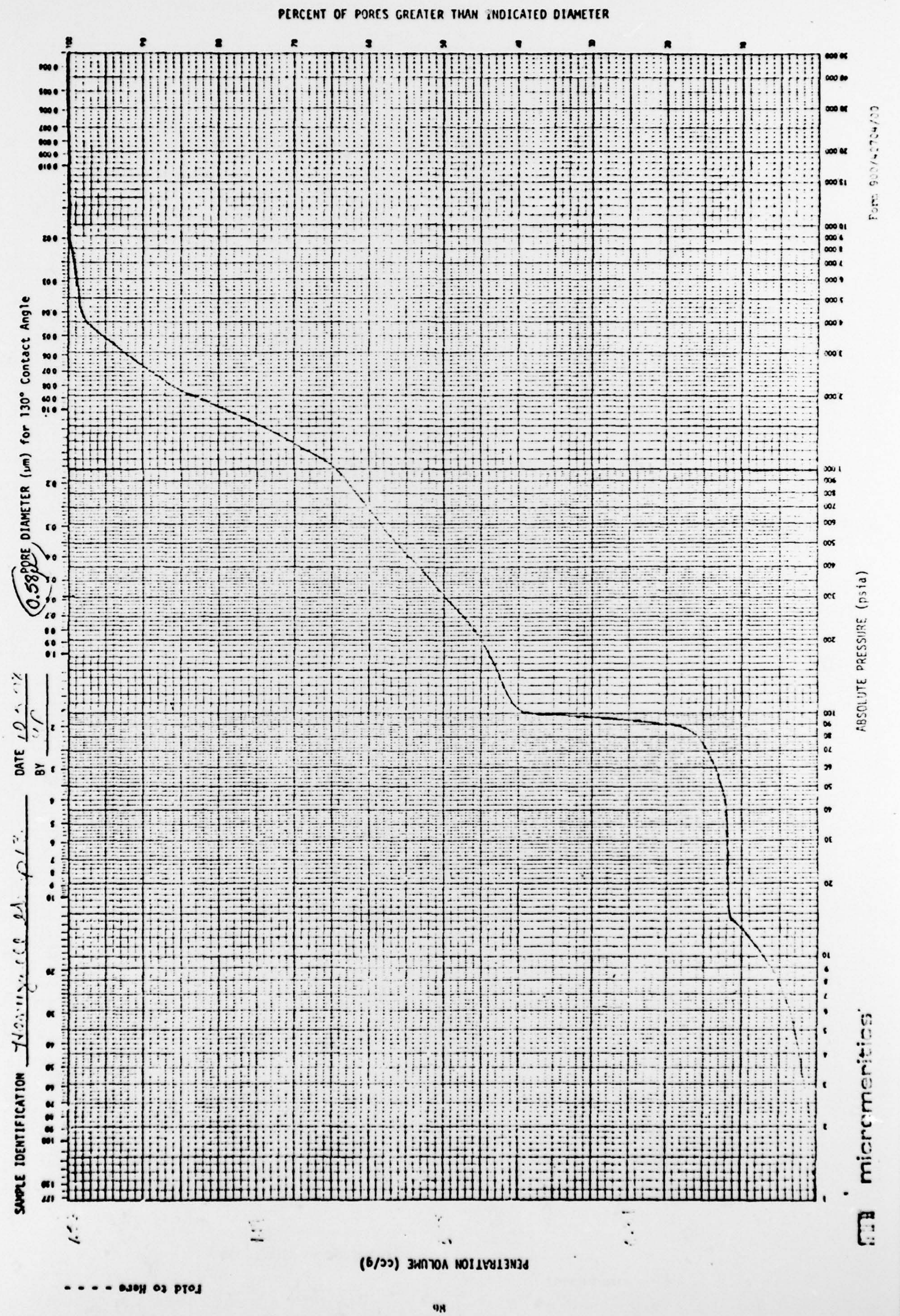
PERCENT OF PORES GREATER THAN INDICATED DIAMETER
SAMPLE IDENTIFICATION
DATE
BY
0.58μ
PORE DIAMETER (μm) for 130° Contact Angle
ABSOLUTE PRESSURE (psia)
PENETRATION VOLUME (cc/g)
Fold to Here
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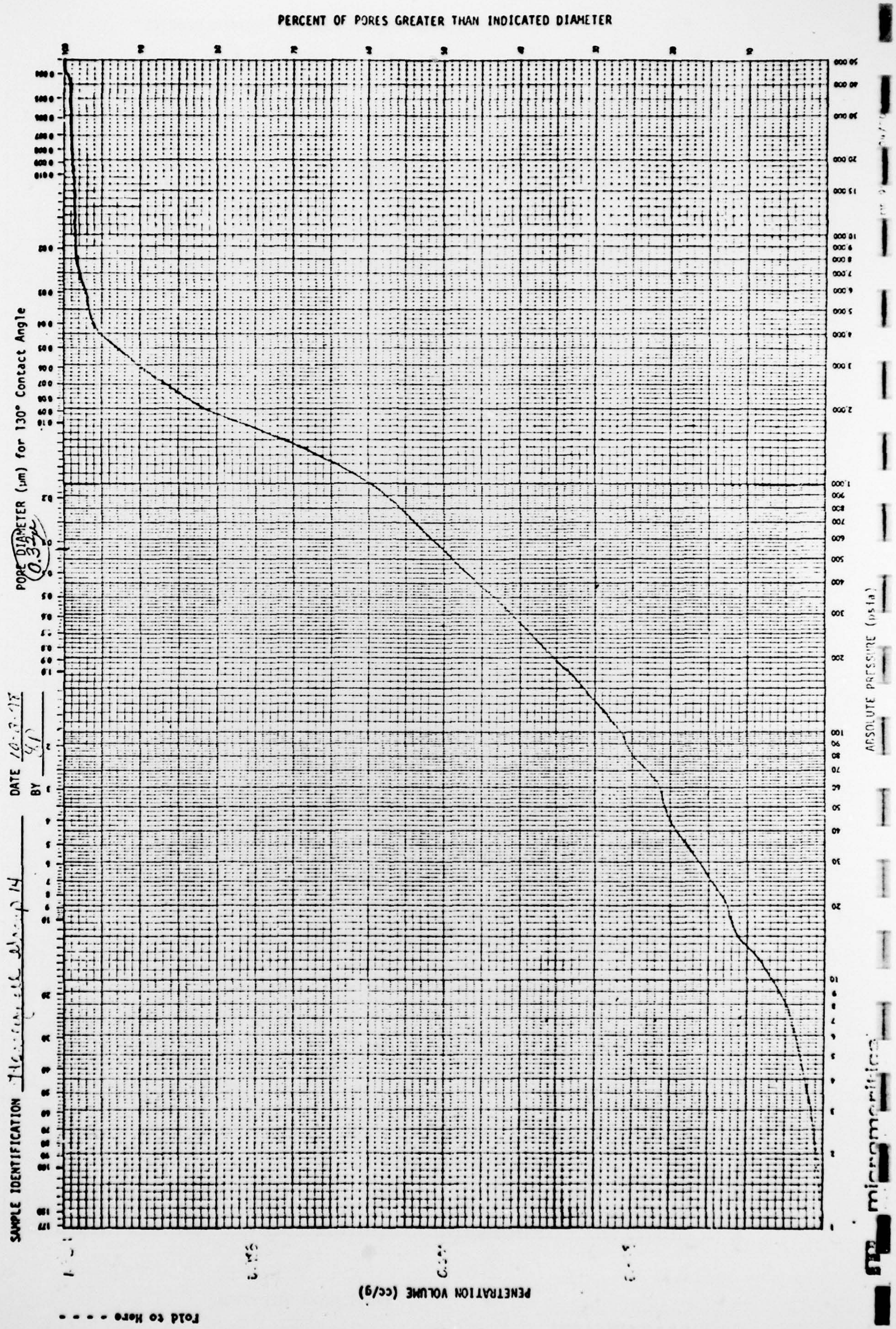
PERCENT OF PORES GREATER THAN INDICATED DIAMETER
PORE DIAMETER (μm) for 130° Contact Angle
ABSOLUTE PRESSURE (psia)
PENETRATION VOLUME (cc/g)
SAMPLE IDENTIFICATION
DATE
BY
Fold to Here
micromeritics

************************ M I C R O M E R I T I C S *****************

M A T E R I A L S A N A L Y S I S L A B O R A T O R Y

MODEL 2100D
SURFACE AREA DATA AND COMPUTATION

DATE RUN 09-11-

SAMPLE IDENTIFICATION: HONEYWELL GROUP 2

MANIFOLD VOLUME: 28.050 ML (STP) EXTRA VOLUME: 131.270 ML (STP)

ADSORBATE: NITROGEN

STATION 3 FLASK NO. 33-31 OUTGAS TEMP. 130 (C) OUTGAS TIME 866. M

W1	19.1357 G	H1	550.5000 MM HG	PS	750.1605 MM HG
W2	18.4375 G	H2	140.9900 MM HG	ALPHA	0.000066 $(MM\ HG)^{-1}$
WS	0.6982 G	TS	77.2400 (K)	S	16.2000 A^2
VS	19.0180 ML				

	EV	P1 (MM HG)	P2 (MM HG)	V (ML, STP)	X (P2/PS)	Y $(ML, STP)^{-1}$
INPUT POINT 1	N	150.2900	21.4380	3.1218	*********	**********
INPUT POINT 2	N	150.0600	49.5900	3.9816	0.0661	0.017778
INPUT POINT 3	N	170.0400	77.1400	4.5554	0.1028	0.025161
INPUT POINT 4	N	190.0200	103.7300	4.9389	0.1383	0.032490
INPUT POINT 5	N	210.5700	129.0400	5.2644	0.1720	0.039464
INPUT POINT 6	N	230.0000	153.0200	5.5505	0.2040	0.046168

SLOPE = 0.2060 INTERCEPT = 0.0041

SURFACE AREA = 20.7192 M^2/G

STANDARD ERROR OF LEAST SQUARES LINE = 0.000075 % ERROR = 0.2344

********** = DATA OUT OF LINEAR REGION OF ISOTHERM,
NOT USED FOR LEAST SQUARES CALCULATION

************************ M I C R O M E R I T I C S ********************

M A T E R I A L S   A N A L Y S I S   L A B O R A T O R Y

MODEL 2100D
SURFACE AREA DATA AND COMPUTATION

DATE RUN 09-13-78

SAMPLE IDENTIFICATION: HONEYWELL GROUP 4

MANIFOLD VOLUME: 28.050 ML (STP)   EXTRA VOLUME: 131.270 ML (STP)

ADSORBATE: NITROGEN

STATION 1 FLASK NO. 0-0   OUTGAS TEMP. 140 (C) OUTGAS TIME 1014. MIN

W1	20.0715 G	H1	550.4000 MM HG	PS	751.0350 MM HG
W2	19.4102 G	H2	147.4600 MM HG	ALPHA	0.000066 $(MM\ HG)^{-1}$
WS	0.6613 G	TS	77.2500 (K)	S	16.2000 A^2
VS	17.8074 ML				

	EV	P1 (MM HG)	P2 (MM HG)	V (ML, STP)	X (P2/PS)	Y $(ML, STP)^{-1}$
INPUT POINT 1	N	150.2300	14.5830	4.7474	*********	**********
INPUT POINT 2	N	180.7100	51.3300	6.1613	0.0683	0.011906
INPUT POINT 3	N	200.9800	86.7100	6.9910	0.1155	0.018670
INPUT POINT 4	N	220.8000	119.1600	7.5767	0.1587	0.024890
INPUT POINT 5	N	240.0300	148.4100	8.0899	0.1976	0.030442

SLOPE = 0.1435   INTERCEPT = 0.0021

SURFACE AREA = 29.9033 M^2/G

STANDARD ERROR OF LEAST SQUARES LINE = 0.000013   % ERROR = 0.0600

********** = DATA OUT OF LINEAR REGION OF ISOTHERM,
NOT USED FOR LEAST SQUARES CALCULATION

************************ M I C R O M E R I T I C S ************************

M A T E R I A L S   A N A L Y S I S   L A B O R A T O R Y

MODEL 2100D

SURFACE AREA DATA AND COMPUTATION

DATE RUN 09-13-78

SAMPLE IDENTIFICATION: HONEYWELL GROUP 5

MANIFOLD VOLUME: 28.050 ML (STP)   EXTRA VOLUME: 131.270 ML (STP)

ADSORBATE: NITROGEN

STATION 2 FLASK NO. 1-1   OUTGAS TEMP. 140 (C)   OUTGAS TIME 1014. MIN

W1	19.7291 G	H1	550.3000 MM HG	PS	751.0350 MM HG
W2	18.9348 G	H2	140.8000 MM HG	ALPHA	0.000066 $(MM\ HG)^{-1}$
WS	0.7943 G	TS	77.2500 (K)	S	16.2000 A^2
VS	19.0477 ML				

	EV	P1 (MM HG)	P2 (MM HG)	V (ML, STP)	X (P2/PS)	Y^{-1} (ML, STP)
INPUT POINT 1	N	150.2500	9.4110	4.6830	*********	**********
INPUT POINT 2	N	180.0800	42.9000	6.3104	0.0571	0.009600
INPUT POINT 3	N	200.4400	77.7500	7.1581	0.1035	0.016133
INPUT POINT 4	N	220.1700	110.0300	7.7828	0.1465	0.022055
INPUT POINT 5	N	240.6200	139.7900	8.3157	0.1861	0.027502

SLOPE = 0.1387   INTERCEPT = 0.0017

SURFACE AREA = 31.0008 M^2/G

STANDARD ERROR OF LEAST SQUARES LINE = 0.000039   % ERROR = 0.2072

********** = DATA OUT OF LINEAR REGION OF ISOTHERM,
NOT USED FOR LEAST SQUARES CALCULATION

************************* M I C R O M E R I T I C S ***********************

M A T E R I A L S   A N A L Y S I S   L A B O R A T O R Y

MODEL 2100D
SURFACE AREA DATA AND COMPUTATION

DATE RUN 09-13-78

SAMPLE IDENTIFICATION: HONEYWELL GROUP 6

MANIFOLD VOLUME: 28.050 ML (STP) EXTRA VOLUME: 131.270 ML (STP)

ADSORBATE: NITROGEN

STATION 3 FLASK NO. 3-3 OUTGAS TEMP. 160 (C) OUTGAS TIME 1014. MIN

W1	19.8309 G	H1	550.9000 MM HG	PS	751.0350 MM HG
W2	18.9269 G	H2	144.2000 MM HG	ALPHA	0.000066 $(MM\ HG)^{-1}$
WS	0.9040 G	TS	77.2500 (K)	S	16.2000 A^2
VS	18.4270 ML				

	EV	P1 (MM HG)	P2 (MM HG)	V (ML, STP)	X (P2/PS)	Y^{-1} (ML, STP)
INPUT POINT 1	N	150.7100	7.5020	4.4263	*********	**********
INPUT POINT 2	N	180.0500	39.6300	6.2219	0.0528	0.008953
INPUT POINT 3	N	200.2100	74.8600	7.1375	0.0997	0.015511
INPUT POINT 4	N	220.4100	107.9900	7.7865	0.1438	0.021568
INPUT POINT 5	N	240.7900	138.4300	8.3368	0.1843	0.027105

SLOPE = 0.1379 INTERCEPT = 0.0017

SURFACE AREA = 31.1705 M^2/G

STANDARD ERROR OF LEAST SQUARES LINE = 0.000037 % ERROR = 0.2000

********** = DATA OUT OF LINEAR REGION OF ISOTHERM,
NOT USED FOR LEAST SQUARES CALCULATION

********************** M I C R O M E R I T I C S **********************

M A T E R I A L S A N A L Y S I S L A B O R A T O R Y

MODEL 2100D
SURFACE AREA DATA AND COMPUTATION

DATE RUN 09-11-78

SAMPLE IDENTIFICATION: HONEYWELL GROUP 8

MANIFOLD VOLUME: 28.050 ML (STP) EXTRA VOLUME: 131.270 ML (STP)

ADSORBATE: NITROGEN

STATION 2 FLASK NO. 7-7 OUTGAS TEMP. 140 (C) OUTGAS TIME 866. MIN

W1	22.0834 G	H1	550.7000 MM HG	PS	750.1605 MM HG
W2	21.5873 G	H2	146.8500 MM HG	ALPHA	0.000066 $(MM\ HG)^{-1}$
WS	0.4961 G	TS	77.2400 (K)	S	16.2000 A^2
VS	17.9288 ML				

	EV	P1 (MM HG)	P2 (MM HG)	V (ML, STP)	X (P2/PS)	Y^{-1} (ML, STP)
INPUT POINT 1	N	150.2800	21.5010	4.5966	*********	**********
INPUT POINT 2	N	150.4000	50.9900	5.7806	0.0680	0.012616
INPUT POINT 3	N	170.0300	79.7300	6.4808	0.1063	0.018350
INPUT POINT 4	N	190.5100	106.9200	7.0048	0.1425	0.023730
INPUT POINT 5	N	210.0700	132.3400	7.4521	0.1764	0.028744

SLOPE = 0.1487 INTERCEPT = 0.0025

SURFACE AREA = 28.7841 M^2/G

STANDARD ERROR OF LEAST SQUARES LINE = 0.000016 % ERROR = 0.0756

********** = DATA OUT OF LINEAR REGION OF ISOTHERM.
NOT USED FOR LEAST SQUARES CALCULATION

************************* M I C R O M E R I T I C S ********************

M A T E R I A L S   A N A L Y S I S   L A B O R A T O R Y

MODEL 2100D
SURFACE AREA DATA AND COMPUTATION

DATE RUN 09-13-7

SAMPLE IDENTIFICATION: HONEYWELL GROUP 10

MANIFOLD VOLUME: 28.050 ML (STP)   EXTRA VOLUME: 131.270 ML (STP)

ADSORBATE: NITROGEN

STATION 4 FLASK NO. C-3   OUTGAS TEMP. 160 (C) OUTGAS TIME 1014. MI

W1	19.6071 G	H1	550.0000 MM HG	PS	751.0350 MM HG
W2	18.8569 G	H2	144.6700 MM HG	ALPHA	0.000066 $(MM\ HG)^{-1}$
WS	0.7502 G	TS	77.2500 (K)	S	16.2000 A^2
VS	18.2956 ML				

	EV	P1 (MM HG)	P2 (MM HG)	V (ML, STP)	X (P2/PS)	Y^{-1} (ML, STP)
INPUT POINT 1	N	150.3400	14.7850	4.1119	*********	**********
INPUT POINT 2	N	180.3300	49.5600	5.5502	0.0660	0.012729
INPUT POINT 3	N	200.4900	84.4700	6.3091	0.1125	0.020086
INPUT POINT 4	N	220.2500	116.6000	6.8546	0.1553	0.026812
INPUT POINT 5	N	240.2300	146.0000	7.3133	0.1944	0.032996

SLOPE = 0.1578   INTERCEPT = 0.0023

SURFACE AREA = 27.1899 M^2/G

STANDARD ERROR OF LEAST SQUARES LINE = 0.000009   % ERROR = 0.0409

********** = DATA OUT OF LINEAR REGION OF ISOTHERM,
NOT USED FOR LEAST SQUARES CALCULATION

************************* M I C R O M E R I T I C S *********************

M A T E R I A L S   A N A L Y S I S   L A B O R A T O R Y

MODEL 2100D
SURFACE AREA DATA AND COMPUTATION

DATE RUN 09-07-78

SAMPLE IDENTIFICATION: HONEYWELL GROUP 11

MANIFOLD VOLUME: 28.050 ML (STP)   EXTRA VOLUME: 131.270 ML (STP)

ADSORBATE: NITROGEN

STATION 4 FLASK NO. C-3   OUTGAS TEMP. 170 (C) OUTGAS TIME 3501. MIN

W1	19.8497 G	H1	550.3000 MM HG	PS	749.2868 MM HG
W2	18.8564 G	H2	146.2100 MM HG	ALPHA	0.000066 $(MM\ HG)^{-1}$
WS	0.9933 G	TS	77.2300 (K)	S	16.2000 A^2
VS	18.0229 ML				

	EV	P1 (MM HG)	P2 (MM HG)	V (ML, STP)	X (P2/PS)	Y^{-1} (ML, STP)
INPUT POINT 1	N	150.5800	10.1170	3.7129	*********	**********
INPUT POINT 2	N	180.2200	40.2100	5.5795	0.0537	0.010164
INPUT POINT 3	N	200.7300	74.5100	6.5934	0.0994	0.016747
INPUT POINT 4	N	220.7200	107.6400	7.2686	0.1437	0.023080
INPUT POINT 5	N	240.6700	138.3000	7.8073	0.1846	0.028993

SLOPE = 0.1438   INTERCEPT = 0.0024

SURFACE AREA = 29.7716 M^2/G

STANDARD ERROR OF LEAST SQUARES LINE = 0.000011   % ERROR = 0.0582

********** = DATA OUT OF LINEAR REGION OF ISOTHERM,
NOT USED FOR LEAST SQUARES CALCULATION

************************* M I C R O M E R I T I C S ********************

M A T E R I A L S A N A L Y S I S L A B O R A T O R Y

MODEL 2100D
SURFACE AREA DATA AND COMPUTATION

DATE RUN 09-14-7

SAMPLE IDENTIFICATION: HONEYWELL GROUP 12

MANIFOLD VOLUME: 28.050 ML (STP) EXTRA VOLUME: 131.270 ML (STP)

ADSORBATE: NITROGEN

STATION 2 FLASK NO. W-5 OUTGAS TEMP. 170 (C) OUTGAS TIME 1040. M

W1	19.3953 G	H1	550.5000 MM HG	PS	745.7995 MM HG
W2	18.6521 G	H2	140.0000 MM HG	ALPHA	0.000066 $(MM\ HG)^{-1}$
WS	0.7432 G	TS	77.1900 (K)	S	16.2000 A^2
VS	19.2001 ML				

	EV	P1 (MM HG)	P2 (MM HG)	V (ML, STP)	X (P2/PS)	Y (ML, STP)$^{-1}$
INPUT POINT 1	N	150.7700	15.3380	3.9883	*********	**********
INPUT POINT 2	N	150.5900	40.8600	5.5149	0.0548	0.010510
INPUT POINT 3	N	170.3200	68.5700	6.3936	0.0919	0.015836
INPUT POINT 4	N	190.9500	95.9700	7.0020	0.1287	0.021092
INPUT POINT 5	N	210.2700	122.0200	7.4789	0.1636	0.026156
INPUT POINT 6	N	220.7800	144.0800	7.9611	0.1932	0.030077

SLOPE = 0.1420 INTERCEPT = 0.0028

SURFACE AREA = 30.0678 M^2/G

STANDARD ERROR OF LEAST SQUARES LINE = 0.000093 % ERROR = 0.4464

********** = DATA OUT OF LINEAR REGION OF ISOTHERM,
NOT USED FOR LEAST SQUARES CALCULATION

*************************** M I C R O M E R I T I C S *************************

M A T E R I A L S   A N A L Y S I S   L A B O R A T O R Y

MODEL 2100D

SURFACE AREA DATA AND COMPUTATION

DATE RUN 09-01-7-

SAMPLE IDENTIFICATION: HONEYWELL GROUP 13

MANIFOLD VOLUME: 28.050 ML (STP)   EXTRA VOLUME: 131.270 ML (STP)

ADSORBATE: NITROGEN

STATION 1   FLASK NO. 100-1   OUTGAS TEMP. 200 (C)   OUTGAS TIME 2641. MIN

W1	18.5515 G	H1	559.5000 MM HG	PS	746.6702 MM HG
W2	18.0151 G	H2	141.6200 MM HG	ALPHA	0.000066 $(MM\ HG)^{-1}$
WS	0.5364 G	TS	77.2000 (K)	S	16.2000 A^2
VS	19.3336 ML				

	EV	P1 (MM HG)	P2 (MM HG)	V (ML, STP)	X (P2/PS)	Y $(ML, STP)^{-1}$
INPUT POINT 1	N	150.3200	18.3650	4.7485	*********	**********
INPUT POINT 2	N	166.9200	49.5400	6.2745	0.0663	0.011326
INPUT POINT 3	N	175.2600	78.0600	7.0292	0.1045	0.016609
INPUT POINT 4	N	185.5000	102.8100	7.5680	0.1377	0.021099
INPUT POINT 5	N	195.3300	124.3700	7.9607	0.1666	0.025105
INPUT POINT 6	N	190.1600	139.6600	8.2438	0.1870	0.027909

SLOPE = 0.1373   INTERCEPT = 0.0022

SURFACE AREA = 31.1956 M^2/G

STANDARD ERROR OF LEAST SQUARES LINE = 0.000020   % ERROR = 0.0998

********** = DATA OUT OF LINEAR REGION OF ISOTHERM.
NOT USED FOR LEAST SQUARES CALCULATION

************************ M I C R O M E R I T I C S ************************

M A T E R I A L S A N A L Y S I S L A B O R A T O R Y

MODEL 2100D
SURFACE AREA DATA AND COMPUTATION

DATE RUN 09-11-78

SAMPLE IDENTIFICATION: HONEYWELL GROUP 14

MANIFOLD VOLUME: 28.050 ML (STP) EXTRA VOLUME: 131.270 ML (STP)

ADSORBATE: NITROGEN

STATION 1 FLASK NO. J-88 OUTGAS TEMP. 140 (C) OUTGAS TIME 866. MIN

W1	19.3589 G	H1	550.7000 MM HG	PS	750.1605 MM HG
W2	18.7267 G	H2	141.5800 MM HG	ALPHA	0.000066 (MM HG)$^{-1}$
WS	0.6322 G	TS	77.2400 (K)	S	16.2000 A^{2}
VS	18.9132 ML				

	EV	P1 (MM HG)	P2 (MM HG)	V (ML, STP)	X (P2/PS)	Y (ML, STP)$^{-1}$
INPUT POINT 1	N	150.5000	15.0960	4.7573	*********	**********
INPUT POINT 2	N	180.0200	48.9200	6.4652	0.0652	0.010790
INPUT POINT 3	N	200.0400	83.0700	7.3698	0.1107	0.016897
INPUT POINT 4	N	220.7800	114.9200	8.0266	0.1532	0.022539
INPUT POINT 5	N	240.1300	144.0800	8.5665	0.1921	0.027751

SLOPE = 0.1336 INTERCEPT = 0.0021

SURFACE AREA = 32.0774 M^{2}/G

STANDARD ERROR OF LEAST SQUARES LINE = 0.000012 % ERROR = 0.0601

********** = DATA OUT OF LINEAR REGION OF ISOTHERM.
NOT USED FOR LEAST SQUARES CALCULATION

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